THE UNIVERSITY OF ALBERTA

THE EFFECT OF BRIEF ISOMETRIC AND ISOTONIC EXERCISE PROGRAMMES ON THE DEVELOPMENT OF STRENGTH AND MUSCULAR ENDURANCE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

SCHOOL OF PHYSICAL EDUCATION

by

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October, 1963

APPROVAL SHEET

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effect of Brief Isometric and Isotonic Exercise Programmes on the Development of Strength and Muscular Endurance" submitted by John R. Richardson in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of the study was to investigate the effects of short bouts of maximal isotonic and isometric contractions on the development of strength and muscular endurance of the extensors of the knee. Subproblems investigated were cross-transfer, hypertrophy, and specificity of training.

Sixty grade ten boys enrolled in a required physical education class at Bonnie Doon high school in the city of Edmonton served as subjects. After initially being measured for girth and fat, strength at angles of 115 degrees and 135 degrees of extension, and muscular endurance (holding time), the boys were randomly divided into three groups, each group containing twenty subjects. One group became the isotonic training group; a second group became the isometric training group; the third group became the control. The exercises were performed once daily, five days a week, for five weeks.

The isometric exercise programme consisted of three six second maximal contractions. One contraction was made with the leg 90 degrees flexed, one at 135 degrees of extension, and one at 165 degrees of extension. The isotonic exercise programme consisted of lifting a maximal weight from the 90 degree flexed position to the 165 degrees extended position three times daily. Each bout required six seconds for the leg to be moved through the specified range. The leg was extended at a constant rate. Results were considered

statistically significant at the .05 level of confidence.

It was concluded that the isotonic exercise group increased significantly over the isometric group ($F=6.26_{.05}$), and both exercise groups increased significantly over the control group ($F=26.95_{.01}$), at the 135 degree angle, when measured for strength. Both exercise groups made a significant increase in strength over the control group ($F=18.91_{.01}$) at the 115 degree angle. The muscular endurance, when measured by employing the same weight for both initial and final tests, increased significantly for the combined isotonic and isometric group scores of the trained leg ($F=4.51_{.01}$) when compared to the control. Cross-transfer of strength was statistically significant for both isotonic and isometric exercise groups at both the 115 degrees (.01 level) and 135 degrees (.01 level) angles. There was no evidence of cross-transfer of muscular endurance. No evidence was found to support either hypertrophy or specificity training.

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to his committee members, Dr. W.D. Smith, Dr. M.L. Howell, Mr. S. Mendryk, and Dr. T. Weckowicz for their guidance and criticism throughout the study.

The assistance of the laboratory technician, Mr. Ken Coupe, in assisting in the testing procedure is gratefully appreciated.

A special acknowledgement is extended to his wife, June, for her encouragement and assistance in drawing the various graphs and diagrams, to Mr. Ken Williamson for his generous aid in the statistical analysis, and to Dr. Stan Rule for his valuable direction in selecting the appropriate statistics for the design.

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CHAPTER I

STATEMENT OF THE PROBLEM

<u>Introduction</u>. In recent years a great deal of interest has been generated in the relative merits of isotonic and isometric exercises and their value when used as forms of exercise programmes.

In the mid-forties, DeLorme (1) proposed a method of weight training against heavy resistance. He believed that heavy resistance and low repetition exercises were necessary to build strength and that low resistance, high repetition exercises were necessary to produce endurance. Later, he felt that "heavy resistance exercises" was the wrong connotation and, therefore, changed his phraseology to "progressive resistance exercises" (2). He also limited the number of sets of repetitions in a training session since he felt the same degree of improvement could be obtained with fewer repetitions. This method has since been successfully employed as a training programme for muscular development.

In 1955, Steinhaus (3) reviewed the findings of Hettinger and Muller on strength development through static contractions and stated:

1. Muscle strength increases an average of 5% per week when the training load is as little as 1/3, or even less, of maximal strength.
2. One practice period per day in which the tension

was held for six seconds resulted in as much increase in strength as longer periods (up to full exhaustion in 45 seconds) and more frequent practices (up to 7 per day).

3. Muscle strength increases more rapidly with increasing intensity of training load up to about 2/3 of maximal strength. Beyond this, increase in training load has no further effect.

. . . .

7. With tension per square cm. of cross section held constant, endurance (holding time) is unchanged with increase in total strength. This indicates an improvement in capillarization paralleling hypertrophy.

8. The rate of increase in strength sometimes varies considerably in the same person when two comparable training periods separated by a long rest period, were compared.

9. There is a ceiling on the development of strength in every muscle. Attainment of this maximum is usually accompanied by pain resulting from some injury within the muscle that stops further increase within the muscle.

10. Maximal strength of any muscle in the body is probably about 3 times the tension demanded of it in everyday activities.

These startling findings immediately raised questions as to which method would produce the greater effect on muscle development. From that date to the present many studies have been performed comparing the effectiveness of isometric and isotonic work in various muscle groups. None of these studies, however, has attempted to compare equated quantitative evidence from the two types of exercise.

A study of paramount importance in the design of the present experiment is the one carried out in 1957 by Rose,

Radzyminski and Beatty (4). This study was carried out through a series of independent experiments performed at four different centres on the effect of brief maximal exercise on the strength of the quadriceps femoris. They stated (4:164):

> It should be noted that our exercise technic differed from that of Hettinger and Muller. Whereas, they employed isometric muscular contractions held for 6 seconds, we employed isotonic contractions maintained for 5 seconds. Our results, however, are in general agreement with theirs.

In the above cited study, Rose _et al._ used an exercise time (5 seconds) which closely approximated that used by Hettinger and Muller (6 seconds). Rose and associates also used a maximal strength lift which they defined as (4:157):

> ...that weight load which the quadriceps could lift from 90 degrees of leg flexion to 180 degrees of leg extension and maintain in complete extension for five seconds, as measured by a metronome or by timed count. This constituted the exercise bout in its entirety.

From this quotation it can be seen that the subjects made only one maximal lift per day which is more commonly employed in the isometric technique, although they moved the mass through a given range, which is an isotonic movement. Actually the movement that the subjects performed was neither strictly isotonic nor isometric but a combination of the two. While the subjects were lifting the weight through the range, they were performing isotonic or dynamic work and while they were maintaining the weight at the end of the range for the remainder of the five seconds to elapse

they were performing isometric or static work.

The changes made from this study to the present study are the two distinct experimental groups, one isotonic and one isometric rather than one intermediary group. In order to better appreciate some of the differences between the effects of the two types of training, the two experimental groups performed the same amount of work with respect to duration of the work phase, percentage of effort involved in the work and range of motion within which the work is performed. The only major difference is the type of exercise programme employed.

<u>The Problem</u>. The purpose of this study is to compare the effects of short term isotonic and isometric exercise programmes on the development of strength and muscular endurance. More specifically the intent is to investigate the relative effects of these two exercise programmes on the development of the strength and muscular endurance of the extensors of the knee.

<u>Limitations of the Study</u>. The subjects used in this study are sixty boys, ages fifteen to eighteen years, enrolled in a compulsory, grade ten, physical education class in Bonnie Doon High School, located in the city of Edmonton. They are randomly assigned to their respective groups.

2. The study consists of two weeks of pre-testing, five weeks of the exercise programme, and two and one-half weeks of post-testing.

3. The muscles involved are the extensors of both the dominant and the opposite legs.

4. The forms of exercise for both isotonic and isometric groups are three six-second maximal contractions, five days a week for five weeks.

5. Increment weights of 1¼ lbs. are added daily to the isotonic group if the maximal lift is performed on all three occasions during the preceding training period.

Definitions. For purposes of this study the following definitions apply:

Strength. Strength is the capacity of a muscle to exert force against a resistance and is measurable only by a single maximal effort (static).

Muscular Endurance. Muscular Endurance or holding time is the ability to maintain a given sub-maximal weight at a given angle over time.

Muscular Contraction. This term refers to the development of tension within a muscle.

Isotonic Contraction. Isotonic or a dynamic contraction occurs when work is performed and the muscle either lengthens or shortens.

Eccentric Contraction. An eccentric contraction refers to a dynamic contraction in which the muscle lengthens.

Concentric Contraction. A concentric contraction refers to a dynamic contraction in which the muscle shortens.

Isometric Contraction. Isometric or a static contract-

ion occurs when the muscle length does not change (theoretically) and technically no work is performed. Heat is dissipated in the form of energy.

DeLorme Method of Exercising. This method consists of three sets of ten repetitions each. The first set is $\frac{1}{2}$ - 10 RM or repetition maximum; the second set is $\frac{3}{4}$ - 10 RM and the final set is 1 - 10 RM. The 10 RM is the maximum weight that a subject can carry in order to complete ten repetitions.

Sub-Problems. Sub-problems, resulting as an outgrowth of the major problems may be stated as follows:

1. Cross transfer of strength and/or muscular endurance from the trained (dominant) to the untrained (opposite) leg.

2. Specificity of muscle training for strength increases.

3. Girth increases in the trained and untrained leg.

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CHAPTER II

REVIEW OF THE LITERATURE

Introduction. In past years much evidence has been presented substantiating the development of strength and muscular endurance through the principle of overload (1, 2,3,4). Many of these studies have followed the dynamic or isotonic type of exercise as outlined by DeLorme (4), in which he proposed a method of weight training against heavy resistance. DeLorme felt that heavy resistance and low repetition exercises were necessary to build strength while low resistance, high repetition exercises produced endurance. DeLorme originally worked with people who had orthopedic and muscular disabilities. He had his patients exert maximum force only once a week. In other training sessions the patients exercised with a 10 RM or ten repetition maximum weight. In 1948, DeLorme (5) changed the terminology of his exercise programme from "heavy resistance exercises" to "progressive resistance exercises" or PRE. At that time he also suggested that the number of sets of repetitions per training session could be cut down since the same degree of improvement could be obtained from fewer repetitions.

In 1953, Hettinger and Muller (6) published their results on static or isometric contractions. Nine male

students participated in seventy-one experiments over an eighteen month period, in which, the training took the form of pulling and holding a predetermined amount of tension against a spring scale by contracting the flexors and extensors of the forearm. Those findings which are pertinent to the present study are as follows:

1. Muscle strength increases an average of 5% per week when the training load is as little as one-third, or even less, of maximal strength.

2. Muscle training increases more rapidly with increasing intensity of training load up to about 2/3 of maximal strength. Beyond this, increase in training load has no further effect.

3. One practice period per day in which the tension was held for six seconds resulted in as much increase as longer periods (up to full exhaustion in 45 seconds) and more frequent practices (up to 7 per day).

4. With tension per square centimeter of cross section held constant, endurance (holding time) is unchanged with increase in total strength. This indicates an increase in capillarization paralleling hypertrophy.

5. The rate of increase in strength sometimes varied considerably in the same person when two comparable training methods, separated by a long rest period, were compared.

In a more recent publication by Hettinger (8) he has slightly revised some of these earlier conclusions. He speaks of a maximal observable training effect of about three to four percent per week rather than the original five percent. He further states:

> This absolute figure changes from muscle group to muscle group but the trend of the curve does not change in different muscle groups.

> It was interesting to find that maximum training effect possible was achieved by using only 40 to 50% of the maximum strength in voluntary isometric muscle contraction (8:25).
>
> . . . .
>
> ...the intensity of the training stimulus must be increased at least every fourteen days as the maximum muscle strength itself increases during this time between the two measurements (8:26).
>
> . . . .
>
> Maintaining a maximum isometric contraction for only one or two seconds is sufficient to provide a training stimulus. When the contraction involves only 2/3 of the maximum strength, it should be maintained approximately four to six seconds, and so on. On the other hand, muscle contractions of every short duration . . . have no effect . . . (8:28).
>
> . . . .
>
> It was found that the maximum increase in muscle strength was obtained with one training stimulus per day (8:29).
>
> . . . .
>
> Also, several maximum contractions one after the other . . . did not increase strength any faster than only one contraction (8:30).

In a practical situation such as the gymnasium or home rather than in a research laboratory it would be hard to accurately gauge varying degrees of strength, but Hettinger alleviates this problem by suggesting (8:31-32):

> . . . in practical application the maximum improvement in the strength of the muscle group being trained can be obtained by giving daily one maximum voluntary isometric contraction against a resistance for one or two seconds.

The findings of Hettinger and Muller (6,8) on the development of strength has prompted many subsequent

investigations which have studied the relative merits of both isotonic and isometric forms of exercise.

Development of Strength. Taylor (9) studied the effectiveness of isometric training programmes in developing strength in dorsal flexion of the right wrist and lateral rotation of the right thigh. Four groups were used; Group I maintained a maximal pull for six seconds; Group II a maximal pull for twelve seconds; Group III a two-thirds maximal pull for six seconds; Group IV a two-thirds maximal pull for twelve seconds. No significant differences were found to exist in any method of producing strength except that the two-thirds maximal pull for six seconds was significantly better than the two-thirds maximal pull for twelve seconds in lateral thigh rotation. All training methods other than the two-thirds maximal for twelve seconds produced a significant improvement in the contractile strength of muscles involved in movement of the right wrist dorsal flexion as compared to the contractile strength of the same muscles of a non-trained control group. The maximum pull for twelve seconds and the two-thirds maximal for six seconds produced a significant improvement in right hand outward rotation strength as compared to the control group. The author has suggested that the mean of the experimental group was always higher than that of the control group, although this increase was not always statistically significant.

Wolbers and Sills (10) measured twenty grade eleven and twelve boys for strength before and after eight weeks of training, with all out effort static exercises of six-second duration each. The experimental group gains were statistically significant in back lift, leg lift, and the combined hand grip test.

Rarick and Larsen (11) compared the relative effectiveness of a single six second bout at two-thirds maximum tension with higher levels of isometric tension held for progressively longer time periods each day in developing static strength in boys. Both experimental groups made gains that were statistically significant and which were significantly higher than the control. The data indicated that once daily two-thirds maximum tension bout was as effective as tension levels above two-thirds maximum and with more frequent exercise bouts.

Rasch and Morehouse (12) equated forty-nine subjects on the basis of height and weight and then these subjects were randomly selected to exercise the right or left arm in one of two groups (1) isotonic progressive resistance exercise consisting of presses and curls and (2) isometric exercises on a strain gauge dynamometer. The exercise programmes were of maximal contractions with a new maximum being established each week. The exercise programmes consisted of approximately one and one-half minutes of actual exercise per day, three times a week for six weeks.

The investigators found that in elbow flexion exercise the mean strength significantly increased 14.38 pounds at the .001 level in the exercised arm. There were no significant changes in strength in the isometric group for this exercise programme. In the arm elevator exercises the isotonic group increased 25.33 pounds at the .001 level while the isometric group made a significant increase of 12.88 pounds in the exercised arm. The increases in strength following isotonic training were greater when the subject was tested in a position in which the exercise was practiced than when tested in an unfamiliar position or by a method unfamiliar to him. Significant gains in hypertrophy were experienced by both methods in both practiced and unpracticed arms and the change was always greater in the isotonic training group. Cross-education gains in strength were statistically significant in both groups with the greater degree of transfer occuring in the isotonic group. The gains in the isotonic group in the cross-education strength were almost as great as in the exercised arm.

With reference to the specificity of strength training, Morehouse says (13:195):

> Repetition of one kind of movement, however, does not increase the strength of the performance of a different type of movement. The pattern of movement must be duplicated to achieve the best training effect. This is the principle of specificity, and it applies not only to the type of movement, but also, to the posture in which the movement is performed. For example, if elbow flexion strength is tested with the elbow at the

> waist and also with the elbow overhead, then a training program instituted with the elbow exercised at the waist, the result afterward will be an increased strength of the performance with the elbow at the waist, but no increase with the elbow overhead.

Other studies showing significant mean increases in strength are those performed by Adamson (14), Littlefield (15), and Crakes (16). All studies, however, are not in agreement with the above findings. Mayberry (17) conducted an experiment on thirty-six subjects at Michigan State University on the effects of isometric exercise and concluded (17:157):

> A maximal or submaximal isometric contraction of a muscle of very short duration done once a day, five days a week for five weeks will not significantly increase the strength of that muscle.

Concerning cross-transfer of strength he says:

> A cross-training effect in the form of an increase in strength of related muscles or symmetrical muscles on the opposite side of the body will not result from such an exercise program.

Howell and Shaw (18) found statistically significant increases in the grip strength of nineteen boys who practiced one daily six-second maximal contraction of the right wrist flexors, for four weeks. The increase was statistically significant for both exercised and non-exercised arms.

Gardner (19) equated sixty subjects on the basis of total strength scores which were determined at angles of 115 degrees, 135 degrees, and 155 degrees. Group I then served as a control; Group II exercised the preferred limb only at 115 degrees of knee extension; Group III only at 135 degrees and Group IV at 155 degrees of knee extension.

Groups II, III, and IV, exercised three times per week for six weeks on Mondays, Wednesdays, and Fridays using a six-second isometric contraction against two-thirds their maximum tension loads. Results show that all exercise groups made significant improvement in total strength (sum of strength scores for the three angles) at the .01 level, and two groups (III and IV) showed significant (.01) increases in strength at their respective training angles. No group improved significantly at any angle other than the one at which it trained. None of the groups made a significant improvement in strength over the controls for the non-exercised leg.

In a review of the literature Berger (20) stated that progressive resistance exercises have differed in the number of sets, the repetitions per set and the proportion of the 10 RM used in the sets. However, no matter what combination was employed in the exercise programme there was a common significant gain within the groups while one programme was not proven superior to another (21,22,23,24,25).

In a study comparing both static and dynamic exercises for strength gains, Lorback (26) compared one group which followed a standard weight training programme for eight weeks with an equated group that practiced static cable tension strength tests. The gains made by the two groups were equal with the exception of the knee flexion test for strength in which the static group made significantly greater

gains. Perkins and Kaiser (27) found the DeLorme 10 RM more effective than a daily isometric exercise in increasing strength of the ankle plantar flexors, the knee extensors and the hip extensors in persons over sixty. After five months the dynamic training group had increased 43.1 percent while the static group had increased 30.8 percent.

Berger (28) found that dynamic training improved dynamic strength more than static training did and static training improved static strength more than dynamic training. Improvements in static strength did not produce corresponding increases in dynamic strength and vice versa.

Scott and Ungar (29) in using an "isometric dynamometer" with adult physiotherapy patients found that the isotonic group was stronger at the end of the first week. At the end of the second week the isometric group was superior (25%) as it was at the end of the third week (30%), and the fourth week (12.4%).

In studies involving different muscle groups of the body, Gersten (30), and Salter (31) stated that there were substantial improvements in strength resulting from both static and dynamic exercise programmes, but, generally, there is no difference in the amount of improvement when the same muscle group was compared.

In 1960, Walters _et al._ (32) investigated the effects of short bouts of isotonic training, isometric training with maximal resistance, and isometric training with two-thirds

maximal resistance. They found that all methods were effective in increasing strength significantly. They also found an improvement in the contralateral unexercised limb as a result of both isometric and isotonic contractions.

Mathews and Kruse (33) compared the effects on the elbow flexors of three consecutive six second maximal contractions using Clarke's Cable Tension Strength Tests with isotonic exercise working to exhaustion on the Kelso-Hellebrandt Ergometer. The weight load was equal to three-sixteenths maximum strength with an exercise rate of one second flexion and one second extension. Sixty subjects exercised isometrically and sixty isotonically with each group being divided into four and exercised two, three, four, and five times per week. It was concluded that since no common regression line existed in any group with regard to strength changes, strength must be dependent on the individual rather than on the type of exercise that he used or the frequency with which he exercised with both the isometric and the isotonic groups. As the exercise frequency increased a greater number of subjects significantly gained in strength. Forty-four of the sixty subjects in the isometric group significantly increased their strength scores while forty-one of the sixty in the isotonic group increased their strength scores. The investigators failed to observe an increase in the strength of the contralateral elbow flexors.

A study which is of utmost relevance to the present study is the one performed by Rose, Radzyminski, and Beatty (34) on the effect of brief maximal exercise on the strength of the quadriceps femoris. The experimenters stated (34:164):

> It should be noted that our exercise technic differed from that of Hettinger and Muller. Whereas they employed isometric muscular contractions held for 6 seconds, we employed isotonic contractions maintained for 5 seconds. Our results, however, are in general agreement with theirs.

In the above cited study Rose et al. used an exercise time (5 seconds) that closely approximated that used by Hettinger and Muller (6 seconds). Their subjects made only one maximal lift per day which is more commonly employed in the isometric technique, although they moved the mass through a given range which constituted an isotonic movement. Their movement, then, actually consisted of an isotonic movement through the specified range and then an isotonic contraction for the termination of the five second period. The following procedure was used in their study (34):

> The initial maximal lift was determined by trial and error. A submaximal lift was succeeded by a supramaximal attempt. The gap between these two figures was closed by such alternate successive attempts until the maximum lift was established. More than three or four lifts were seldom necessary to establish the 5 second value. The maximal lift was defined as that weight load which the quadriceps could lift from 90 degrees of leg flexion to 180 degrees of leg extension and maintain in complete extension for five seconds, as measured by a metronome or by timed count. This constituted the exercise bout in its entirety (34:157).

. . . .

> From this maximal value increments of $1\frac{1}{4}$ pounds could be lifted at each exercise period until the plateau maximum was established. Psychological or psychophysiological factors were capable of mitigating against this increment. The weight increment was the same regardless of the initial strength of the muscle . . . (34:164).

. . . .

> At each succeeding exercise period an effort was made to increase progressively the weight lifted by a constant increment. If the increment could not be lifted, the weight of the preceding period was attempted; if this also resulted in failure, the next preceding value was attempted. No more than three attempts were made at any given period (34:157).

The results indicated that over a period of eight weeks a plateau strength of from eighty to four hundred percent of the original strength resulted in these patients and normal subjects. With the weight increment used it was found that there was a consistent increase to the plateau. In the normal well motivated individual, the strength of the unexercised quadriceps was almost exactly the same as that found in the exercised muscle. In others, the cross-transfer was ten to fifteen percent less. No evidence of hypertrophy was found by circumferential measurements of the thigh taken four inches and eight inches above the superior border of the patella.

Development of Muscular Endurance. Asmussen (1949) as reported by Petersen (35) found that sustained isometric work appeared to exert a greater effort on muscular endurance to static contractions than intermittent isometric work.

Dennison, Howell, and Morford (36) found that isometric exercise programmes increased muscular endurance (chinning and dipping) following eight weeks of thirteen isometric contractions, each held maximally for six seconds, twice a week. Howell, Kimoto, and Morford (37) measured the improvement in muscular endurance, as measured by two minutes work on a bicycle ergometer with a fourteen kilogram resistance. Both the weight training group and the Commander Set group improved significantly at the .01 level; however, no statistically significant differences existed between the exercise groups.

Swegan (38) studied the effects of training by static contractions (six seconds at two-thirds maximum) and dynamic contractions or weight training (10 RM programme), three days a week for ten weeks, on the development of muscular endurance. It was found that muscular endurance, which was the ability to maintain a standard metronome rate in elbow flexion and extension, was improved significantly at the .01 level by the weight training group. The isometric group had only improved significantly (.05 level) from the left elbow extension. However, when composite scores were calculated the isometric group had a statistically significant increase at the .05 level for gain in muscular endurance. The final scores showed no statistically significant differences between the two training regimes.

Howell and Shaw (39) evaluated the effect of eight

maximal isometric contractions against an immovable bar. The experimental group showed statistically significant increases at the .01 level in terms of muscular endurance over a six week period (chins, dips, and arm strength).

Studies Comparing Isometric and Isotonic Programmes for Development of Strength and Muscular Endurance. Asa (40) found that a repetitive isometric group (20 contractions daily for 6 seconds, 4 days a week for 12 weeks) gained a significantly higher degree of strength than a single isometric group (one contraction a day over the same days). When these two groups were compared to an isotonic group (DeLorme technique), Asa found that the repetitive isometric gained a significantly higher degree of endurance than the single isometric group and there was a significant difference between the isometric and isotonic groups. However, there was no significant difference between isotonic group and the single isometric group in the development of endurance. Training was carried out four days a week for twelve weeks.

Baer (41) found that maximal increase in isometric tension was produced by isotonic exercises when performed at the slow rate of ten per minute, although heavy resistance isometric exercise performed at the same rate of ten per minute produced an increase in isometric tension that was nearly as great. Increases ranging from +115 to +133 percent were produced by all the exercises used, whether heavy resistance isometric, heavy resistance isotonic, or low

resistance complex motion.

Lawrence, Meyer, and Mathews (42) investigated the effectiveness of isometric exercise as compared with isotonic exercise in the development of muscle strength in the quadriceps femoris of twenty-three subjects. Before the exercise programme all subjects were given an initial test to determine the ten repetitions maximum. One group performed progressive weighted isometric exercises (30 second maximum isometric contraction of the right quadriceps femoris, repeated 10 times with 15 second rest intervals). The other group exercised by the DeLorme method for the right quadriceps femoris. Their training period covered nineteen exercise days. It was found that the development of strength in the quadriceps muscle by isometric exercise was less than that by isotonic according to percentage of increase in weight of the exercise loss when both were performed against progressive maximal resistance. The average difference over the period of four weeks was fourteen percent. The staying power or the endurance component of the quadriceps muscle underwent greater increase with the isometric than with the isotonic exercise employed, according to comparative performance of the two groups in tests with maximally resisted contractions of brief and long duration. With regard to cross-transfer, the investigators reported that there was an increase in strength of the unexercised limbs for both groups, and that the increase in strength of the muscles

of the unexercised limb was greater when the exercised limb was trained by isotonic contractions.

Liberson and Asa (43) studied the effectiveness of three groups. One group followed the DeLorme method, one performed one daily six-second isometric contraction, and one performed twenty daily isometric contractions of six-second duration. The muscle under consideration was the abductor digiti quinti of the hypothenar eminence of one hand. It was found that the isometric groups experienced greater changes in muscular endurance that did the isotonic groups. Liberson and Asa stated that there was no effect of cross-education to the contralateral muscle as a result of any of the three training programmes utilized in the study.

Rodgers (44) had one group perform weight training exercises three times a week, six to ten repetitions, thirty minutes each day for a period of six weeks. The static group exercised by holding one MR for six seconds in prescribed positions three times weekly for six weeks. Results show that throughout the experiment the static group was superior to that of the concentric group on the sit-ups, the push-ups and pull-overs. The concentric group, however, slightly exceeded the static group at the end of the second week in curls. The gain for the groups was not statistically significant.

Meadows (45) trained an isometric and an isotonic group three days a week for ten weeks. He concluded that both

exercise groups improved significantly (.01 level) in the back lift, and in the speed of the offensive football charge, and the force of the offensive football charge. The isotonic group showed significant improvements in chins at the .01 level compared to the isometric group. There were no other statistically significant differences between the groups. In the training period the two groups worked for the same period of time.

Petersen (35) investigated the effect of muscle training by static, eccentric, and concentric contraction. Muscle strength was measured by the strain gauge using the Darcus dynamometer.

The Darcus dynamometer was also used in the endurance test, where the time a subject could hold fifty percent of the maximum isometric torque was determined. The twenty to thirty-six day training programme of the seventeen young men and seventeen young women was one of the following forms of exercise: one daily maximum isometric contraction; ten daily maximum isometric contractions; ten daily eccentric muscular contractions or 15 minutes of daily heavy dynamic work (riding a bicycle ergometer). The isometric training procedures consisted of five second maximal contractions with repeated contractions made every 30 seconds. The eccentric contractions were made by forcing the limb into extension during five seconds in spite of resistance by the subject. The dynamic training was carried out on Krogh's

bicycle ergometer. The results when compared to the controls showed that the one daily maximum isometric contraction had no effect on the isometric muscle strength; ten daily maximum isometric contractions had a tendency to increase the isometric strength, while ten daily maximum eccentric contractions had no effect on the strength of the muscles. Heavy dynamic work increased isometric strength by twelve percent in the females and twenty-three percent in the males. Endurance did not change in any of the programmes and there was no cross-transfer effect; that is, training of muscles on one side did not modify the strength of contralateral muscle groups.

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CHAPTER III

METHODS AND PROCEDURE

The subjects were sixty grade IX boys, enrolled in the required physical education class in Bonnie Doon High School, located in the city of Edmonton. The mean age of the subjects was sixteen years and four months with a standard deviation of 8.3 months. The subjects were not actively engaged in any physical activity other than that carried on during the physical education class. All testing and training procedures were carried out from 11:20 A.M. to 12:05 P.M. each school day. Periods were held at the same time on Saturday for anyone missing the regular test schedule. No testing or training was carried out on Sunday.

The initial testing programme covered a period of two weeks or ten days plus an additional week or five days for repeating the measurements on fifteen subjects randomly selected from the class. The Pearson product-moment correlation coefficient was used to establish the test-retest reliability of the measurements. The experimental training was arranged and carried out during the next five weeks or twenty-five sessions, and the final testing sessions on the following twelve days.

The following measurements were made on both legs.

1. Strain gauge strength at 135 degree and 115 degree angles.

2. Girth measurements taken eight inches above the superior border of the patella.

3. Subcutaneous skinfold thickness of the front thigh taken eight inches above the superior border of the patella.

4. Muscular endurance holding time with five-eighths strength at 135 degree angle.

All the girth and fat measurements were determined by the physical education laboratory technician and all the strength and muscular endurance measurements were determined by the author.

At the end of the initial test period the subjects were randomly divided into three groups. One group was designated to be the Isotonic training group, and the second group was termed the Isometric training group, and the third was the Control group. During the training period all subjects were engaged in the regular class activity except for the short time that the experimental subjects were excused to perform their daily exercises. The class activity during the first three weeks was volleyball, and tumbling during the last two weeks.

Apparatus: The exercises for both experimental groups and the strength and muscular endurance measurements for all subjects were carried out on a modified rehabilitation exercise table.

Strain Gauge: The SR4 strain gauges were constructed as a Wheatstone bridge. With the measurement arm set at a

given angle (115° or 135°) the tension on the strain gauge was set at 100 lbs. This tension corresponded to zero lbs. tension on the recorder, (A Texas Instrument Co. Servoriter, model P.R.S.). The application of differential tension to the measurement arm resulted in the deflection the recording needle measured. When the strain gauge was not in use it was detached from the measurement arm.

Calibration of the Strain Gauge: The strain gauge with a range of 0-500 lbs. was suspended from the ceiling and a 100 lb. weight was attached to the lower end. The resultant deflection of the needle was then set at zero on the recorder chart. Weights were then systematically added to the lower end of the strain gauge and the corresponding deflection of the needle was marked on the recorder.

Potentiometer: A potentiometer was permanently inserted in the measurement arm (figure II). The resistor of this potentiometer was in series with two other resistors situated in the control box. The recorder needle was set at zero and any change in the angle of the measurement arm resulted in a one line deflection of the recorder needle on the chart paper. When the potentiometer was not in use as a measuring device it was detached from the control box (figure I).

Control Box: A control box was constructed which was connected in series with either the strain gauge or the potentiometer, and the recorder (figure I). A variable knob located on the front of the box was turned by the experimenter

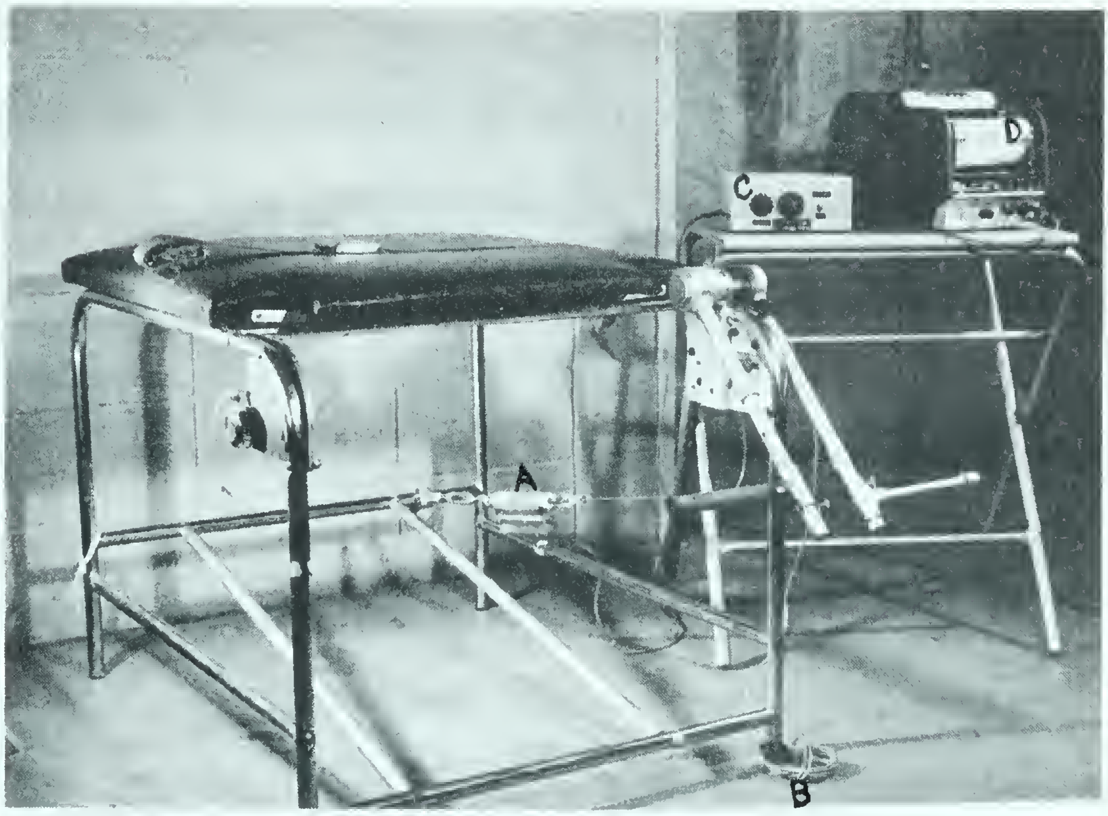

FIGURE I. Equipment Set Up for Measurement of Static Strength

A - Strain gauge (attached to recording device)
B - Potentiometer lead (not attached)
C - Control box
D - Recorder

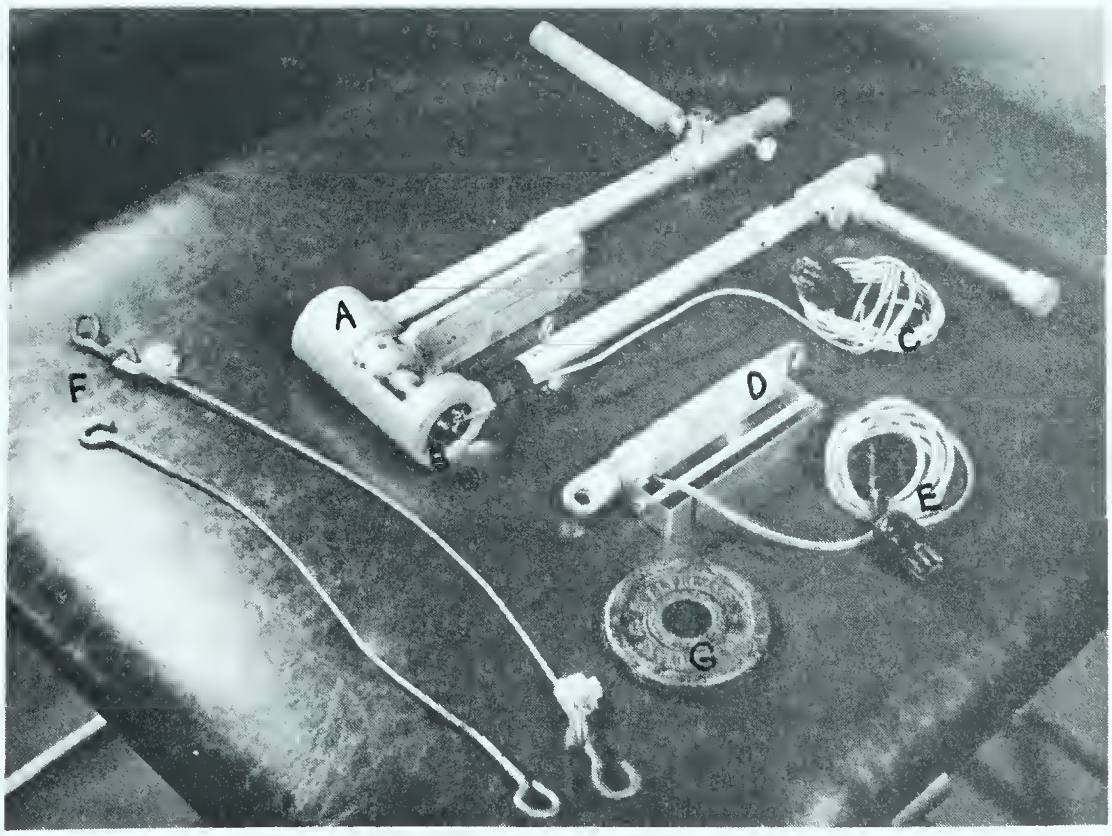

FIGURE II. Measurement Equipment

A - Training and measuring arm
B - Potentiometer inserted in measurement arm
C - Potentiometer cable
D - Strain gauge
E - Strain gauge cable
F - Cables for angles of 115^{o} and 135^{o}
G - $1\frac{1}{4}$ lb. increment weight

to one of two positions. When in position 1 the strain gauge apparatus was connected in series with the recorder; when in position 2, the potentiometer was connected to the recorder.

Measurement of Girth and Subcutaneous Fat: In order to determine a fat corrected girth measurement the following measurements were taken.

Gross Thigh Girth: The subject stood in an erect position with his feet shoulder width apart. The tester placed the tape around the thigh at a point perpendicular to the long axis of the leg, eight inches above the superior border of the patella. A Mitchell constant tension tape was used. All measurements were read to the nearest one-tenth centimeter. Measurements were made on both legs, (figure III).

Subcutaneous Fat: A skinfold measurement of subcutaneous fat was taken in order to establish that any resultant girth changes were due to training and not due to changes in subcutaneous fat deposits. The following measurement prodedure (1, 2) was used with the Harpenden Skinfold Caliper (figure IV) as the measurement instrument.

1. The subject placed the leg to be measured ahead of the opposite leg in a semi-flexed relaxed position. The bulk of the body weight was carried on the opposite leg.

2. The tester grasped the fold of skin with the thumb and forefinger of one hand and lifted it away from the underlying bone and muscle.

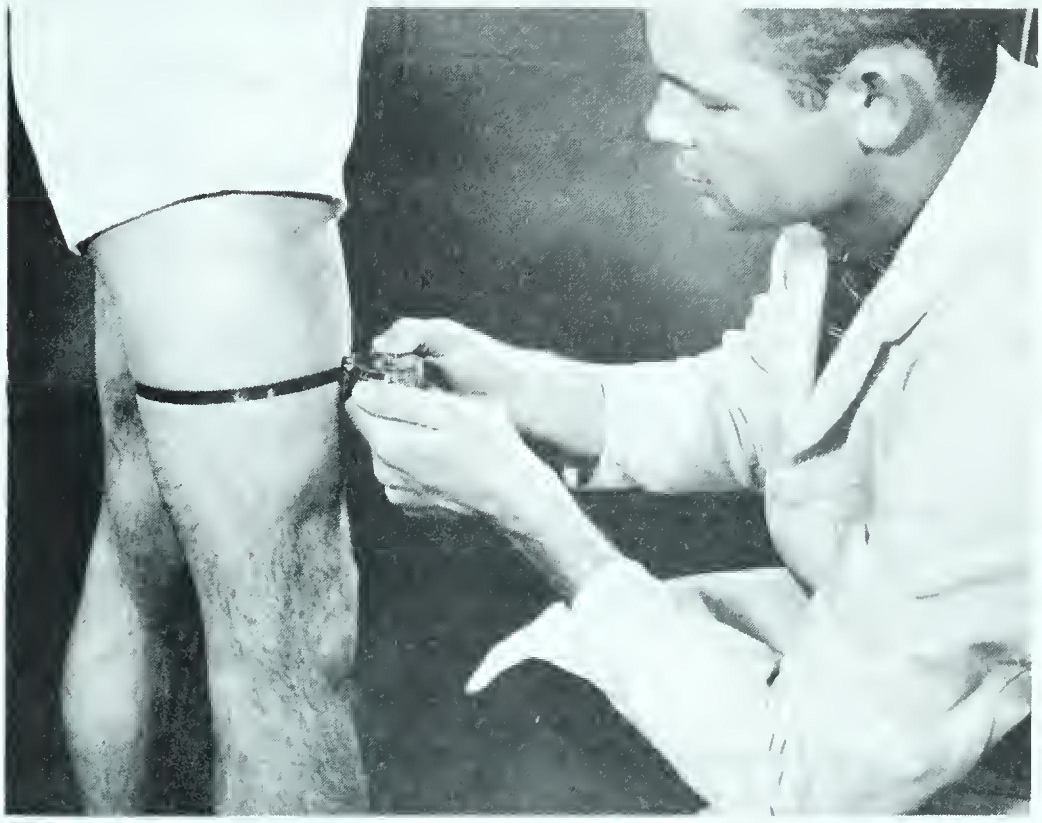

FIGURE III. Gross Girth
(Mitchell, constant tension, tape)

FIGURE IV. Measurement of Front Thigh Skinfold with Harpenden Skinfold Caliper

3. The contact surfaces of the caliper were placed on the skin one centimeter below the thumb and forefinger and perpendicular to the leg.

4. The pressure of the thumb and forefinger was slowly released until only the caliper remained in contact with the skin (figure IV).

5. The reading was taken to the nearest one-tenth millimeter and the average of three successive readings was recorded.

Measurement of Strength: The measurement arm was set at the desired angle (115° or 135°) and the subject was seated with the back of his knee placed against the end of the exercise table with the leg hanging loosely. A safety belt, which was attached to the table, was then drawn tightly across the subjects thighs to prevent lifting of the hips. The subject was told to grasp the outer back edges of the table and to lock his elbows in a straightened position. This fixed upper body position was maintained throughout the measurement. The subject was then instructed to place his ankle against the ankle bar and contract maximally against it. This static measurement was repeated for both legs at the two angles and was recorded on the chart (figure V). The 135 degree angle was measured for both legs on the same day and the 115 degree angle was measured the next day.

Measurement of Muscular Endurance: The preliminary

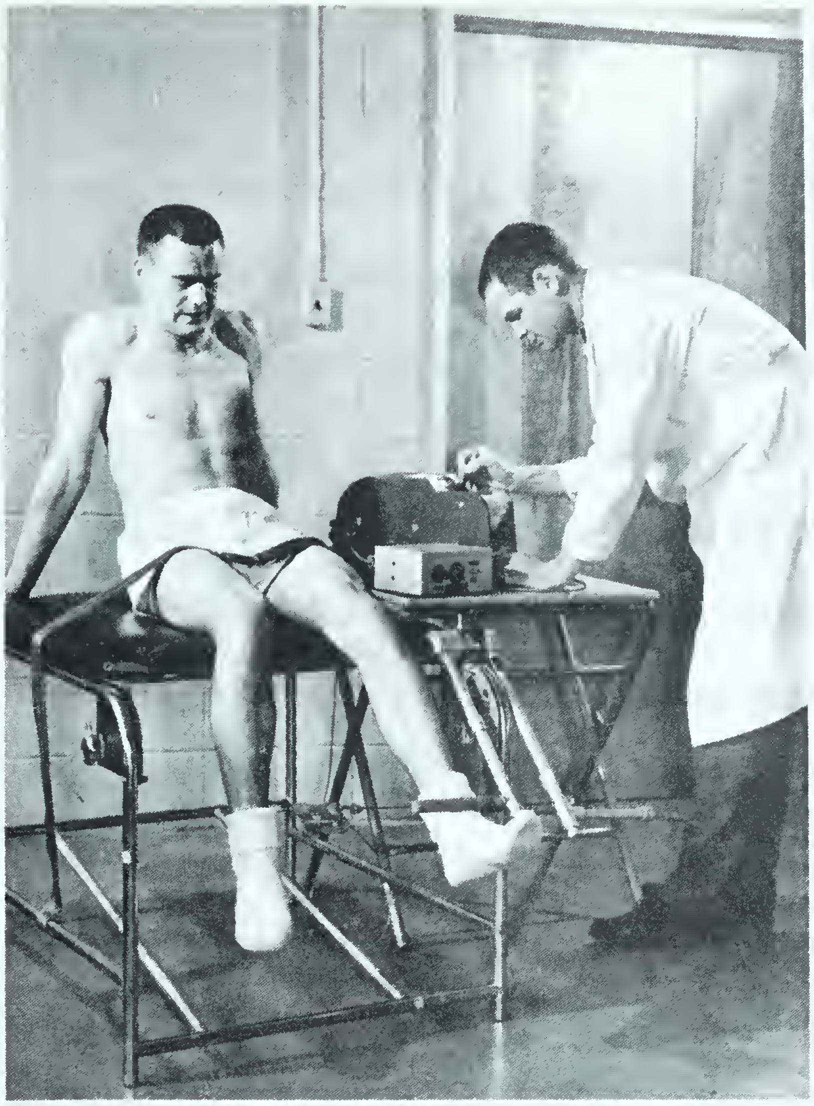

FIGURE V. Recording of Static Strength

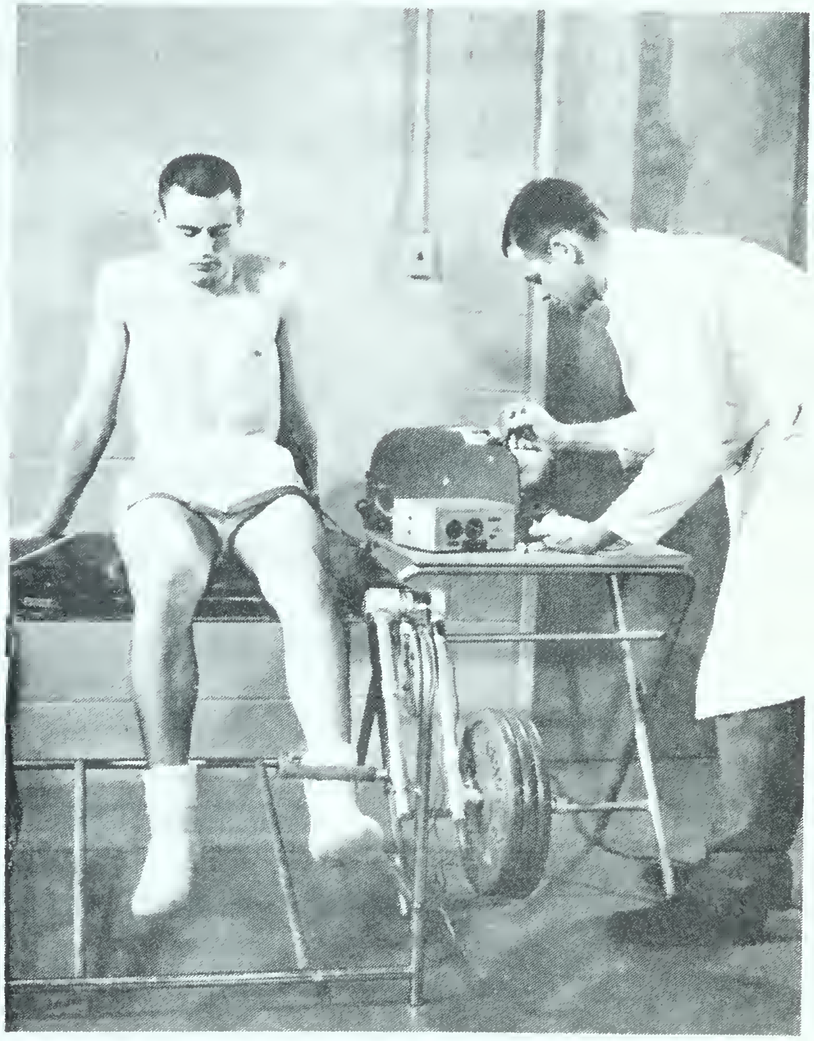

FIGURE VI. Recording of Holding Time Endurance

FIGURE VII.

)perator Holding Weight After Isotonic Contraction

positioning and securing of the subject was identical with that outlined above for the measurement of strength. The measurement arm was set at the 135 degree angle. Weights, equivalent to five-eighths of the strength measured at that angle for the appropriate leg were placed on the outside carrying arm. At a given signal the pin holding the measurement arm at the 135 degree angle was removed as the subject took the force of the weight on his ankle. The time, in seconds, that the weight could be supported at this angle was recorded by a stop watch. When the recorder needle was deflected one line, that is, the measurement arm fell a distance of 10 degrees, the test was terminated. Only one leg was tested on a given day. The opposite leg was tested on the following day.

Description of Exercises: Isotonic Group.

Starting Position 1. The subject was sitting, with his hands gripping the outer edges of the table with his elbows in the straightened locked position. The safety belt was pulled tightly across his upper thighs to prevent lifting of the hips.

2. The lower leg hung loosely from the knee over the end of the table and the ankle was hooked behind the ankle bar which was at right angles to the table top.

Movement 1. At a given signal the subject lifted a maximal weight, that is, the greatest weight that could be success-

fully lifted once, from the 90 degree resting position to the extended 165 degree angle. When the 165 degree angle was reached a bell, attached to the exercise arm, rang signifying this attainment. The subject was instructed that the complete movement was to be carried out at a constant rate and was to take six seconds. At the end of the timed extension the experimenter lifted the weight while the subject relaxed his leg and returned it to the resting position (figure VII). The initial weight was determined from the initial strength measured at the 135 degree angle. This weight was always less than the initial strength and had to be adjusted by trial and error (5).

2. Each subject performed three maximal weight extensions each day Monday through Friday with a thirty second rest period between successive bouts.

3. Each day an increment weight of $1\frac{1}{4}$ lbs., as used in the Rose, Radzyminski, and Beatty study (5), was added to maintain a maximal weight. If the subject was unable to handle the added increment weight on any day, that is, he failed to reach maximal extension in any of the three six-second bouts, then a $1\frac{1}{4}$ lbs. weight was removed for the next trial. No weight was added on any successive day until this criterion was attained.

Description Of Exercises: Isometric Group.

Starting position 1. Subject was sitting, with his hands gripping the back outer edges of the table, with his

elbows in the straightened locked position. The safety belt was pulled tightly across his upper thighs to prevent lifting of the hips.

2. The lower leg hung loosely from the knee over the end of the table and the ankle was hooked behind an ankle bar which was in one of three positions: (1) 90 degrees to the table top (2) partly extended knee position (135°) (3) extended knee position (165°).

Movement 1. At a given signal the subject made a maximal static contraction against the fixed bar for six seconds in one of the above mentioned positions. The seconds, which were marked off by a metronome, were counted out by the experimenter. At the end of the six-second period the subject relaxed his leg and returned it to the resting position.

2. Each subject performed one six-second maximal contraction at each of the three above mentioned positions with a thirty second rest period between each bout.

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CHAPTER IV

RESULTS AND DISCUSSION

The following reliability coefficients were obtained from the Pearson product-moment correlation coefficient determined on fifteen subjects randomly selected from the class.

TABLE 1

Test-Retest Reliability Coefficients

Variable	Number of Subjects	Reliability Coefficient
Strength	15	.91
Muscular Endurance	15	.87
Girth	15	.98
Fat	15	.96

Each of the reliability coefficients was statistically significant beyond the .01 level of confidence (for 15 subjects $r \geq 0.558$).

Analysis of Variance-Summary

Strength 135°

	Sums of Squares	Degrees of Freedom	Mean Square	F
Groups	21014.32	2	10507.16	16.60*
Error (a)	36089.55	57	633.15	
Legs	1400.84	1	1400.84	6.98**
Groups x Legs	1048.31	2	524.16	2.61
Error (b)	11432.85	57	200.58	
Total	70985.87	119		

* significant at .01
**significant at .05

Orthogonal Comparisons

Comparison	F ratio	Significance
Difference between group means of the two experimental groups compared to the control	26.93	.01
Difference between the group means of the two experimental groups	6.26	.05
Difference between the trained and untrained legs for all three groups	3.05	
Difference between the trained and untrained legs of the two experimental groups.	2.18	

In order to compare the trained and untrained legs of the two experimental groups with the control, the following test was employed:

Dunnett's Test for Comparisons with a Control

Comparison	Mean Difference (lb.)	Significance
Trained Legs	62	.01
Untrained Legs	42.5	.01

It is noted that from this point on in the results the scores that are compared are the differences between final and initial scores. These scores, in group form, are then compared with other difference scores.

There is a significant difference between the combined scores of the three groups. The combined score refers to the adding together of the scores for the trained and the untrained legs in a given group. This difference is significant at the .01 level ($F= 16.60_{.01}$). Upon further analysis it was determined that the combined scores of the two experimental groups differed significantly from the control group ($F= 26.93_{.01}$). The improvement in strength in the isotonic group was also significantly greater ($F= 6.26_{.05}$) than that of the isometric group when the combined scores were considered. Both the isotonic and the isometric groups when considered together differed significantly from the control (.01 level) for both the trained and the untrained legs. The difference between the two experimental groups when the trained and the untrained legs were compared was not of statistical significance.

<u>Analysis of Variance - Summary</u>

Strength 115°

	Sums of Squares	Degrees of Freedom	Mean Square	F
Groups	12747.82	2	6373.91	10.73*
Error (a)	33860.	57	594.05	
Legs	896.54	1	896.54	6.94**
Groups x Legs	560.64	2	280.32	2.17
Error (b)	7359.82	57	129.12	
Total	55425.47	119		

* significant at .01 level
** significant at .05 level

Orthogonal Comparisons

Comparison	F ratio	Significance
Difference between group means of the two experimental groups compared to the control	18.91	.01
Difference between the group means of the two experimental groups	2.55	
Difference between the trained and untrained legs for all three groups	1.92	
Difference between the trained and untrained legs of the two experimental groups	2.41	

Dunnett's Test for Comparison With a Control

Comparison	Mean Difference (lb.)	Significance
Trained Legs	51	.01
Untrained Legs	37.5	.01

There was a significant difference ($F = 10.73_{.01}$) between the combined scores of the three groups and a significant difference ($F = 18.91_{.01}$) between the combined scores of the two experimental groups when they were compared to the control. A significant F of 6.94 at the .01 level provided evidence that there was a significant difference between the legs of the groups considered together. It was also found that the grouping of the trained legs of the two experimental groups differed significantly from the control group (.01 level) and the same difference was found in the untrained leg (.01 level).

Nothing may be said statistically comparing the trained and untrained legs of the two experimental groups.

Analysis of Variance - Summary

Muscular Endurance I

	Sums of Squares	Degrees of Freedom	Mean Square	F
Groups	2612.27	2	1306.14	
Error (a)	120731.72	57	2118.10	
Legs	6264.07	1	6264.07	13.51 *
Groups x Legs	2127.80	2	1063.90	2.30
Error (b)	26431.13	57	463.53	
Total	158156.99	119		

* significant at .01 level

Orthogonal Comparisons

Comparisons	F ratio	Significance
Difference between group means of the two experimental groups compared to the control	1.21	
Difference between the group means of the two experimental groups		
Difference between the trained and untrained legs for all three groups	4.51	.01
Difference between the trained and untrained legs of the two experimental groups		

Dunnett's Test for Comparisons with a Control

Comparison	Mean Difference (lb.)	Significance
Trained legs	37.4	.05
Untrained legs	3.3	

There was no statistically significant difference between the combined scores of the three groups. However, there was a significant difference ($F = 13.51_{.01}$) between the legs of the three groups. Further analysis gives evidence that there was a significant difference ($F = 4.51_{.01}$) between the trained and the untrained legs when the three groups were combined together. No significant statement can be made concerning the difference that there may have been between the trained and the untrained legs of the two experimental groups. Dunnett's test showed a significant difference (.05 level) between the trained legs of the two experimental groups when compared with the control group.

Analysis of Variance - Summary

Muscular Endurance - II

	Sums of Squares	Degrees of Freedom	Mean Square	F
Groups	13.62	1	13.62	
Error (a)	91311.77	38	2402.94	
Legs	11068.52	1	11068.52	8.09*
Groups x Legs	132.65	1	132.65	.10
Error (b)	51958.83	38	1367.34	
Total	154485.39	79		

* significant at .01 level

Since the comparisons are already orthogonal there is no need for further comparisons. The analysis shows that there is no statistically significant difference between the combined scores of the two groups. The difference between the trained and the untrained legs of the two groups was statistically significant ($F = 8.09_{.01}$), but nothing can be said statistically concerning the legs by groups interaction.

Analysis of Variance - Summary

Girth

	Sums of Squares	Degrees of Freedom	Mean Square	F
Groups	12.32	1	12.32	1.56
Error (a)	300.00	38	7.89	
Legs	1.93	1	1.93	1.28
Groups x Legs	.52	1	.52	
Error (b)	57.08	38	1.50	
Total	371.85			

Since the analysis is orthogonal, no further comparisons were made. There were no statistically significant F ratios for the girth scores.

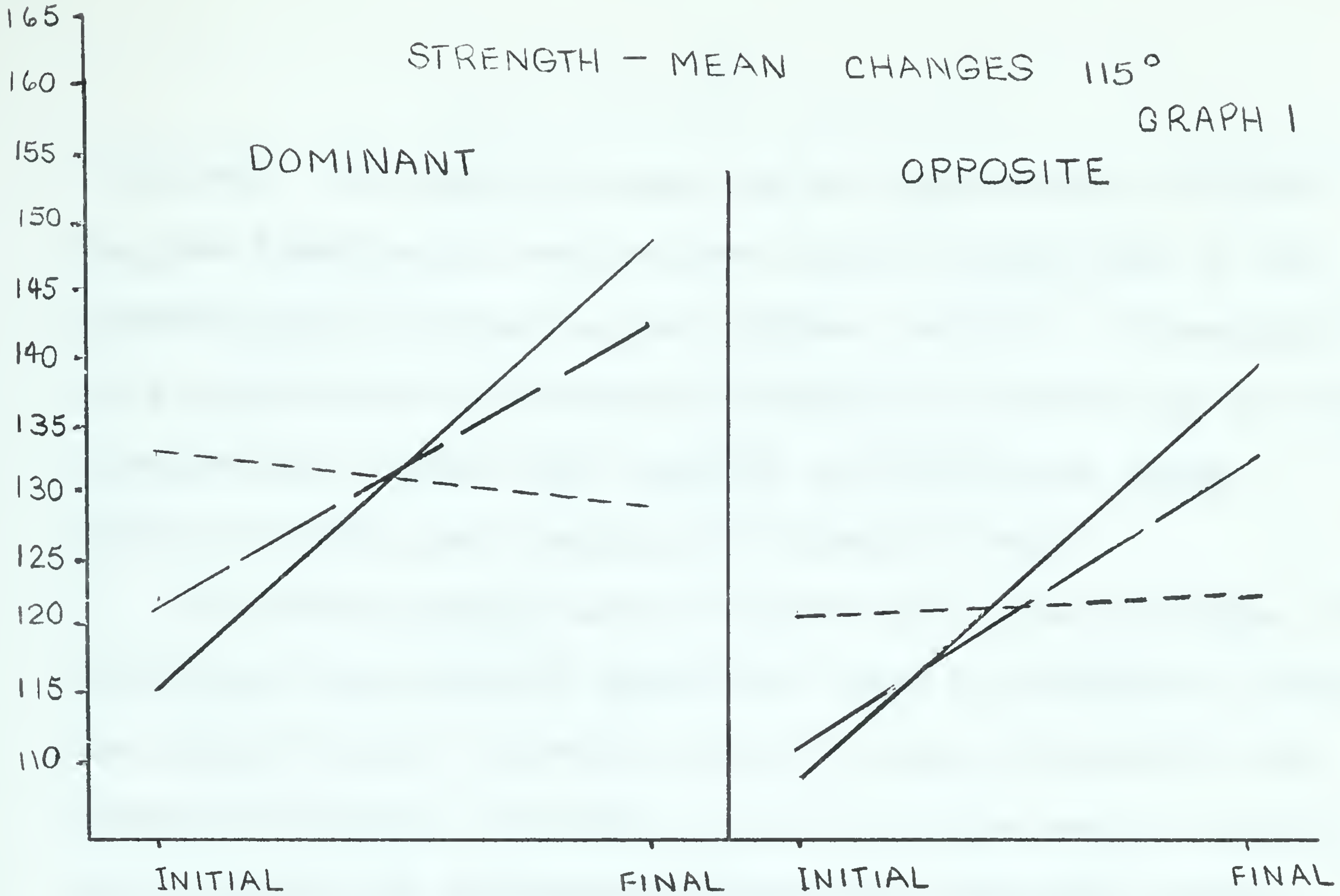
Discussion. It is a generally accepted fact (1) that a comparison of values of exercise by contrasting various muscle groups is not feasible. Different muscle groups are employed in different ways in daily living and probably,

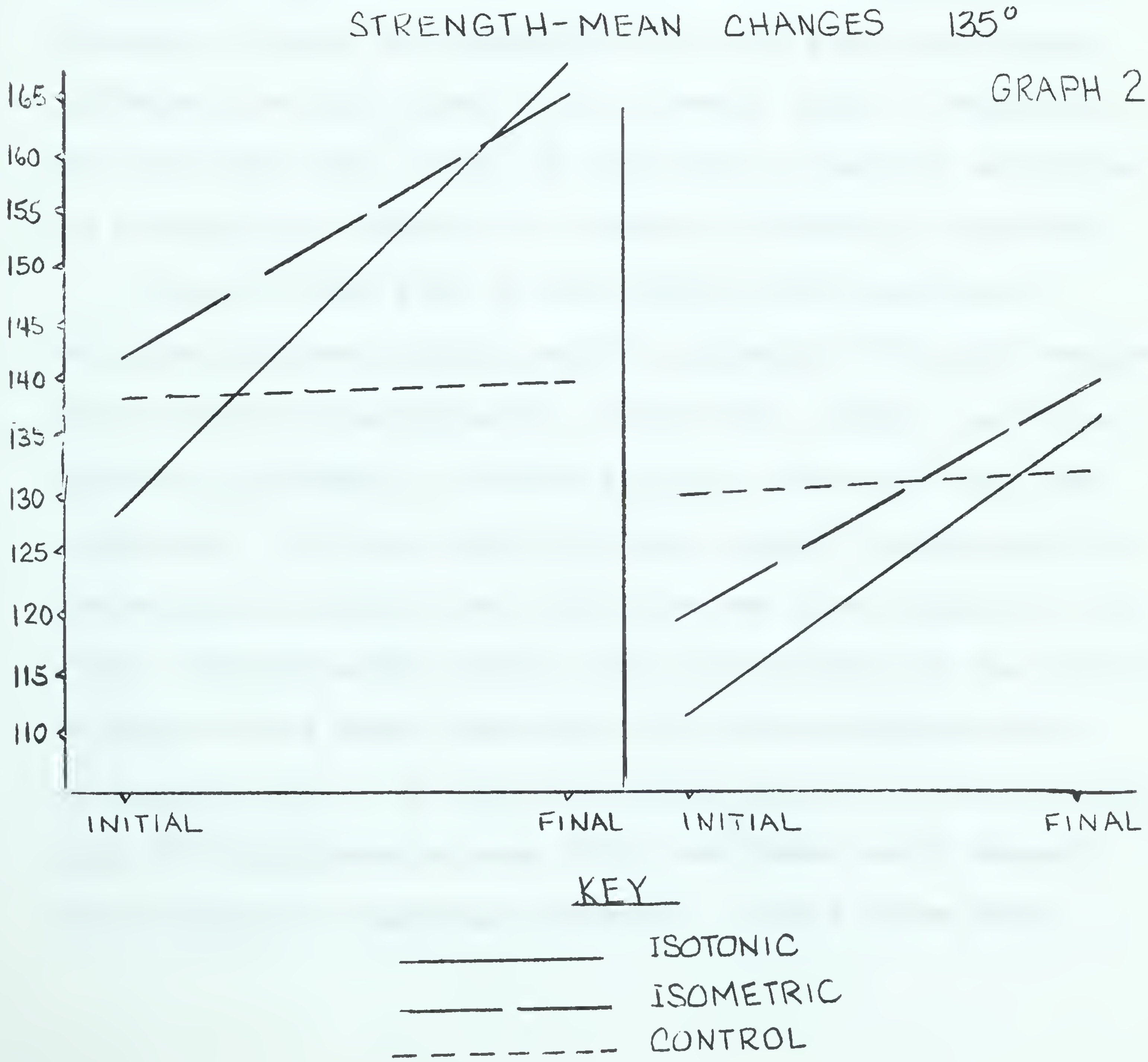
therefore, have different levels of trainability at any given time. In the light of this statement the following discussion concerns itself with an evaluation of the present findings in relation to other studies performed on the quadriceps muscles. It is not possible, however, to limit the discussion to similar or identical types of exercise programmes since these are few or non-existent.

Strength. At the 135 degree angle the strength of the isotonic group increased significantly over the isometric group when the combined scores were considered and both groups increased significantly over the control group. However, at the 115 degree angle, although both exercise groups increased significantly over the control group, there were no statistically significant differences between the two exercise groups. In the study by Gersten (2) it was found that improvement in isometric tension was almost identical for the quadriceps muscle whether treated isometrically or isotonically. Lawrence et al. (3), however, found that an average maximum increase in the weight carried over a four week exercise period was seventy-six percent for the isotonic group while the increase for the isometric group was sixty-two percent or fourteen percent less. In the present experiment the mean increase in the isotonic group was twenty-nine percent at the 115 degree angle while in the isometric group it was seventeen percent. At the 135 degree angle the increase was thirty-two percent

in the isotonic group and sixteen percent in the isometric group. The above percentages were based on the trained leg only. When the trained legs of the experimental groups were combined it was found that they differed significantly from the control. The same significance was found in the untrained legs of the experimental groups when they were compared with the control. Petersen (4) has reported increases of twenty-three percent on the isometric strength of males between the ages of eighteen and thirty years of age who were trained on heavy dynamic work. His results are generally comparable with those of the present study. Petersen (4), however, did not find any significant increase from maximal isometric contractions that were held for five seconds and repeated every thirty seconds. The reason for this finding is not known. When the graphs of the mean increases are inspected (Graphs 1 and 2), the general trends of the increases can be readily seen.

Muscular Endurance. When the same weight as was initially used to measure the holding time endurance (5/8ths initial strength), was again used for the final test, it was found that there was no statistically significant differences between the composite scores of the three groups. The trend for the trained leg (Graph 4), however, suggested a mean increase for both isotonic and isometric groups. The combined isotonic and isometric scores for the trained legs differed significantly from the control at the


STRENGTH — MEAN CHANGES 115°
GRAPH I
DOMINANT
OPPOSITE
165
160
155
150
145
140
135
130
125
120
115
110
INITIAL
FINAL
INITIAL
FINAL


STRENGTH-MEAN CHANGES 135°
GRAPH 2
165
160
155
150
145
140
135
130
125
120
115
110
INITIAL
FINAL
INITIAL
FINAL
KEY
ISOTONIC
ISOMETRIC
CONTROL

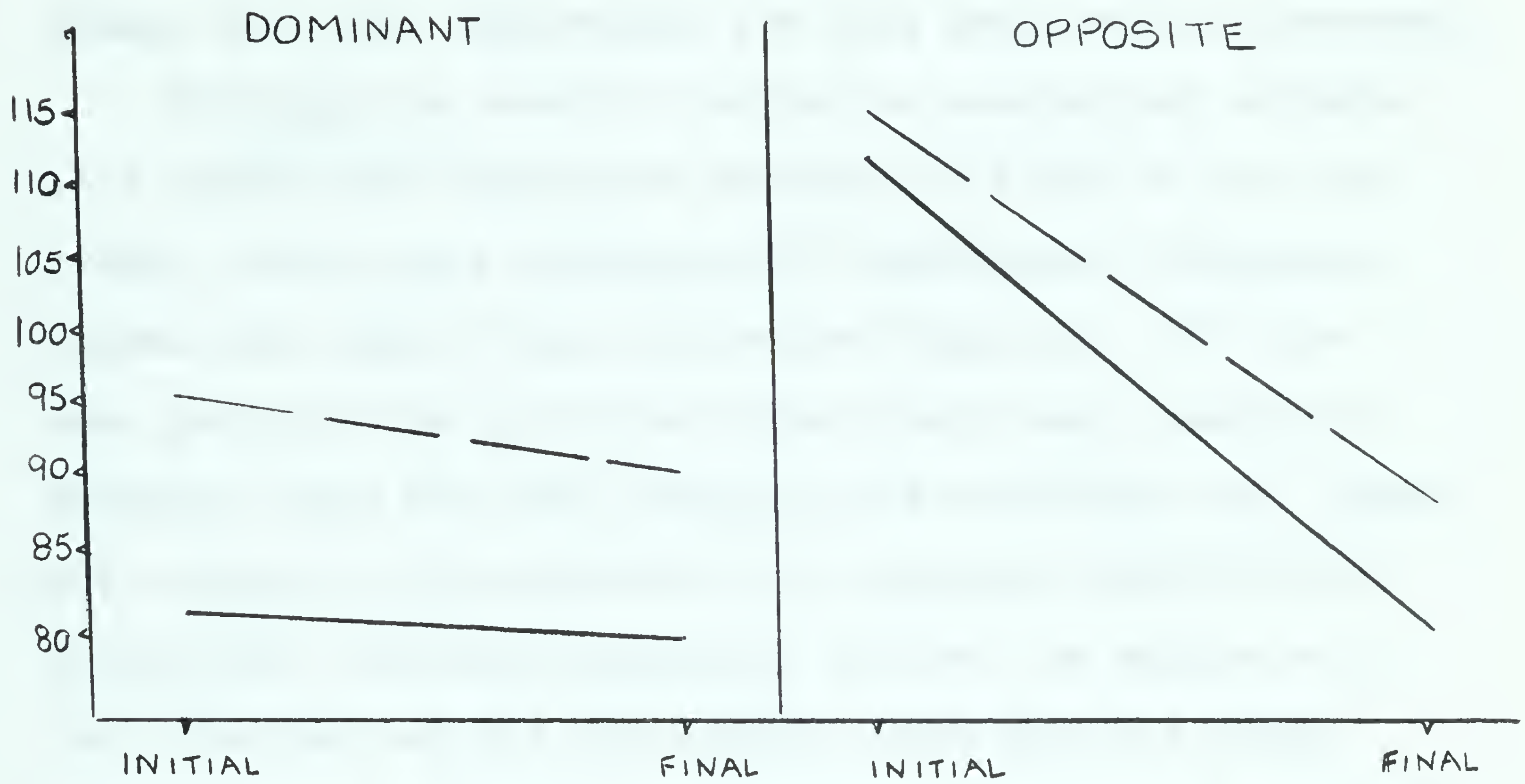
.05 level. The mean increase for the isotonically trained leg was found to be twenty-three percent while that of the isometrically trained leg was sixteen percent. No statistically significant differences between the trained legs of the experimental groups when compared to the control group could be found upon analysis by Dunnett's test.

The above results are in accord with those of Swegan (5) who found that muscular endurance, based on composite scores, was significantly increased after training by isotonic and isometric methods. He also found that there was no statistically significant difference between the exercised groups. However, it must be remembered that his exercise routine differed from that used in the present study. Petersen (4), on the other hand, found no increase in muscular endurance as a result of isotonic or isometric training programmes.

Since it was felt by the author that increases in muscular endurance might produce somewhat different results when measured independently of strength changes due to an exercise programme, a second muscular endurance test was conducted. In this test the final weight that was used in determining holding time endurance was five-eighths of the final strength score rather than five-eighths of the initial strength score which was employed in the endurance test discussed above. In this procedural method it was believed that the difference scores then considered would measure only changes in muscular endurance. Since there were

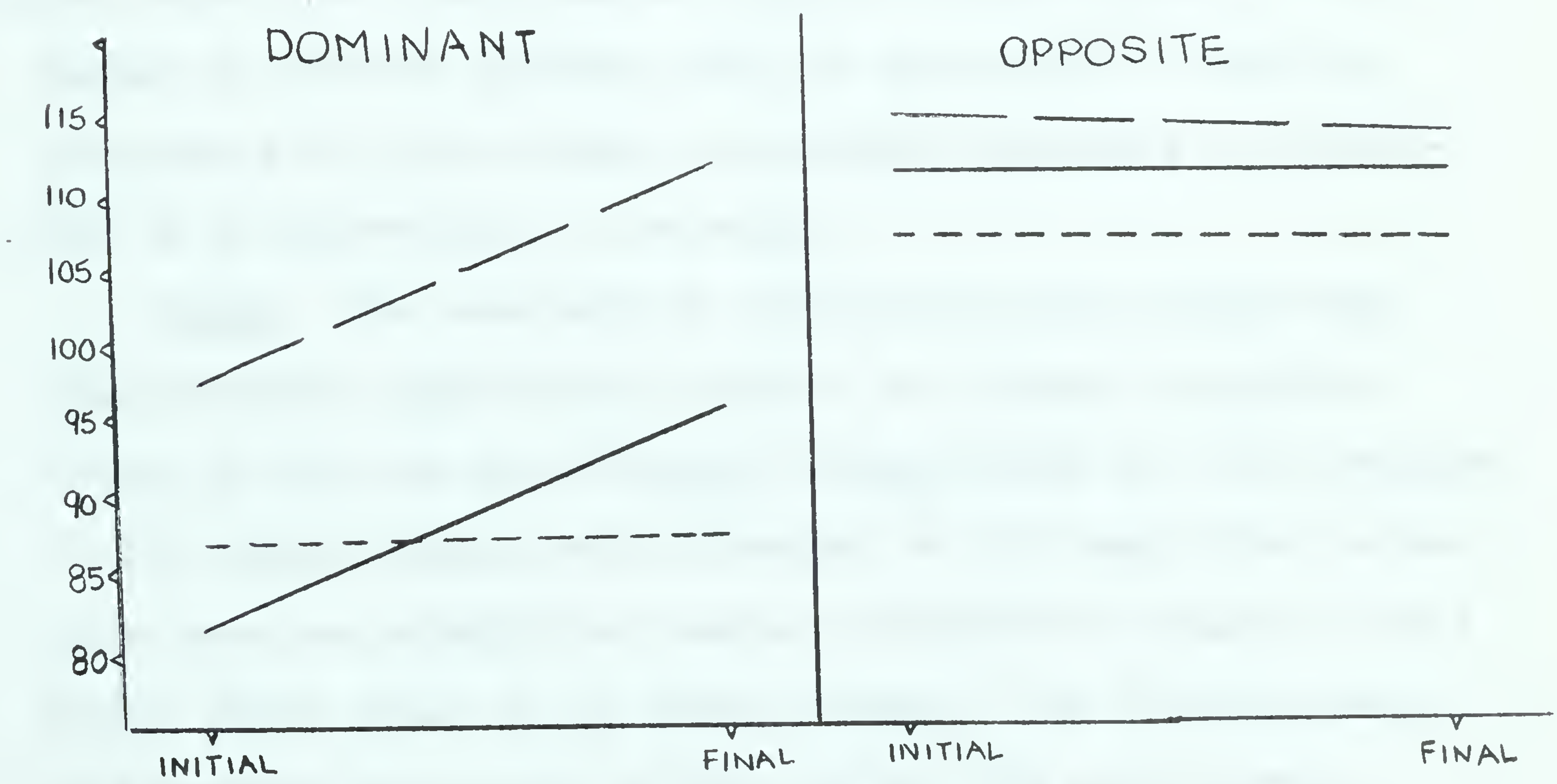
MEAN CHANGES—HOLDING TIME (sec) WT. OF FINAL STRENGTH

GRAPH 3



MEAN CHANGES—HOLDING TIME (sec) WT. OF INITIAL STRENGTH

GRAPH 4



KEY

ISOTONIC (solid line)
ISOMETRIC (long dashes)
CONTROL (short dashes)

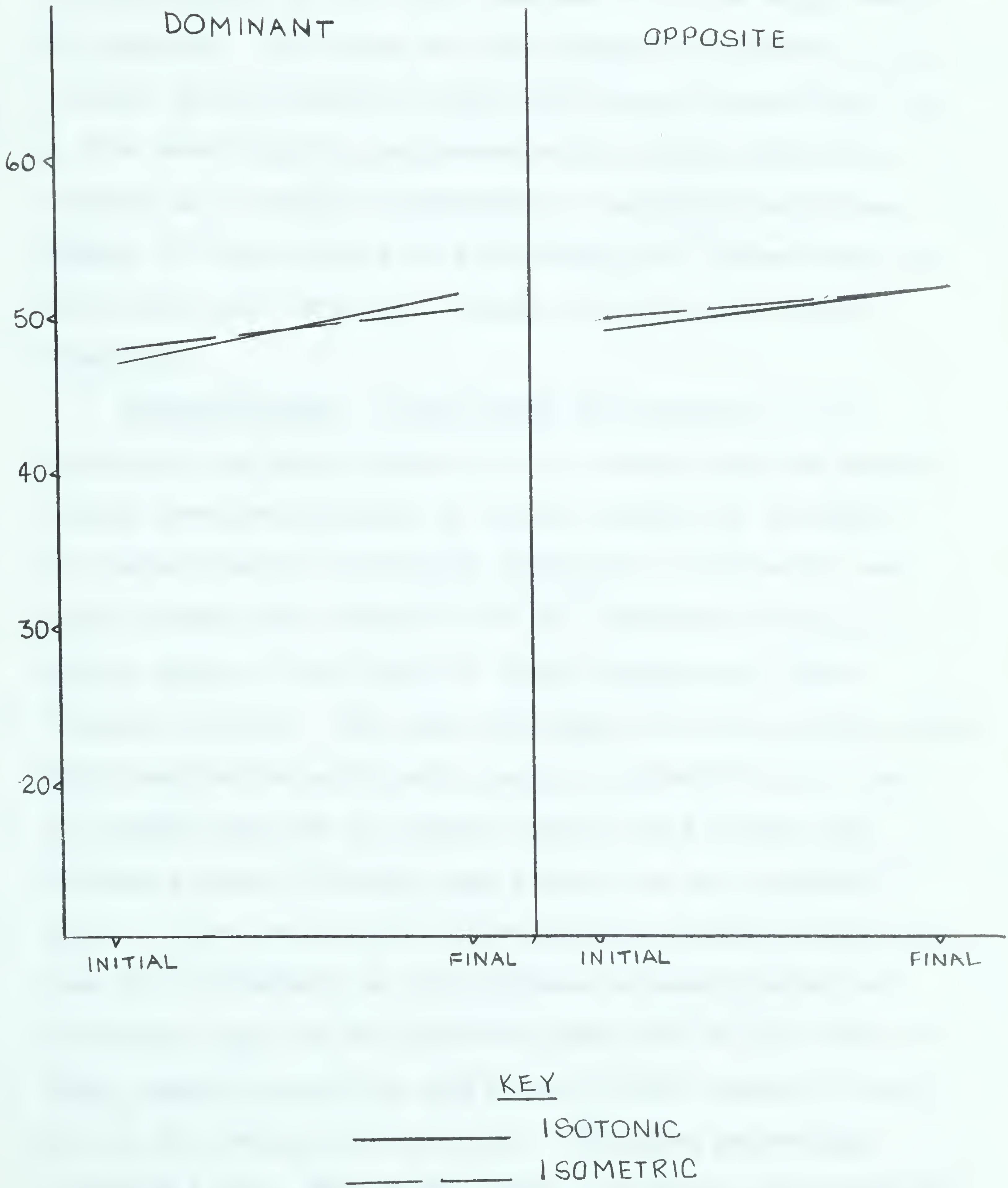
relatively no changes in the strength scores of the control group, the final measurement for this group was not recorded.

Although the results provided no statistical evidence of a significant difference between the total of the two groups, there was a statistically significant difference between the legs of the two groups (Graph 3). This was most probably due to the fact that there was a resultant downward trend for both groups in the untrained leg. Since the strength of the untrained leg increased significantly in both the training programmes, and yet the endurance of the untrained leg did not improve, even when its change was evaluated in terms of accompanying changes in strength (Graph 4), this downward trend under the new conditions was to be expected. The graph of the trained leg mean changes indicated that there was no change in either group. This seemed to further indicate that in this kind of training programmes the improvement in muscular endurance is dependent on an improvement in strength.

Girth. The analysis of variance did not provide any statistically significant evidence of changes in girth in either of the two experimental groups (Graph 5). The results of the control group were discarded on the basis that, since there were no strength or muscular endurance changes in this group, there would be no girth changes. The findings were in agreement with those of Rose *et al.* (6) and Liberson and Asa (7) who did not find any resultant hypertrophy in

MEAN CHANGES — GIRTH

GRAPH 5

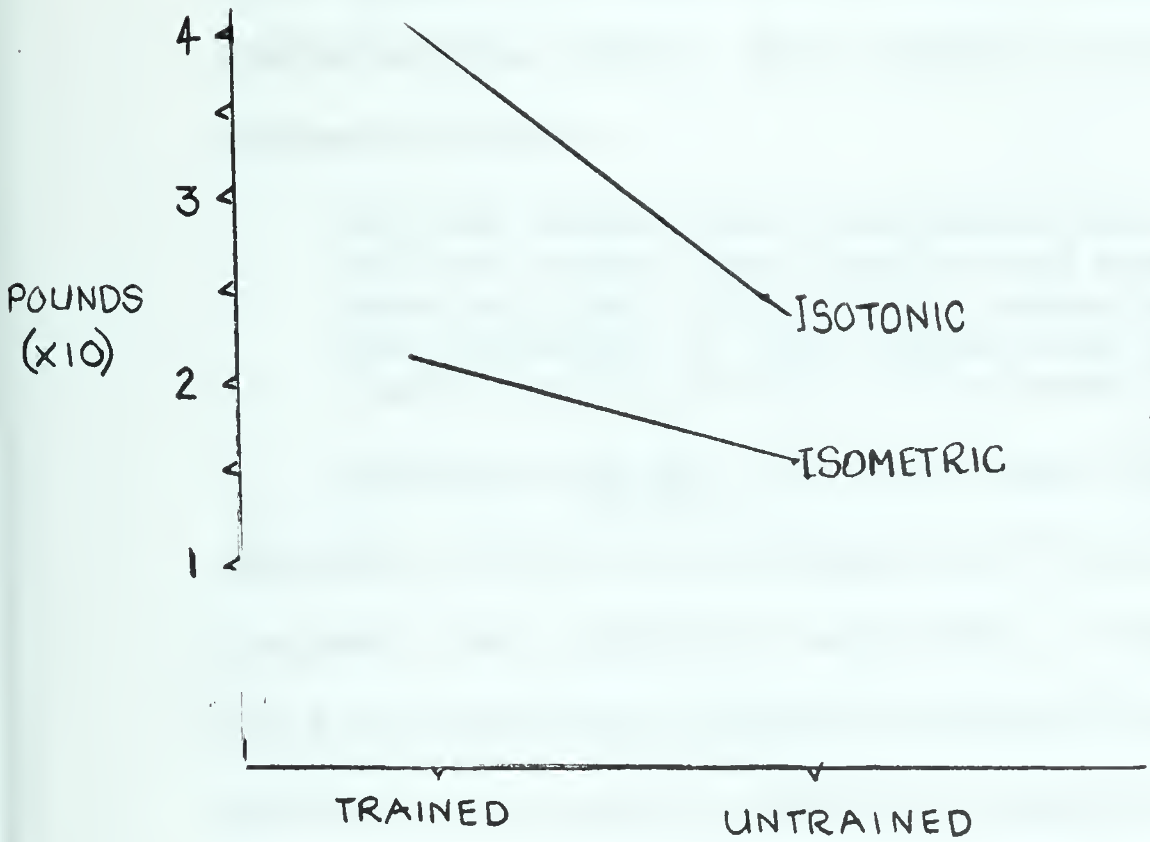


their subjects when they were measured in a similar location. DeLorme (8) has reported as much as two and one-half inches of hypertrophy of the thigh muscles in six to eight weeks of training. His study was with regard to patients. In another study, Berger (9) did not find any hypertrophy in a five week training programme on the right quadriceps muscles as a result of progressive resistance exercises. Swegan (5) also failed to find significant hypertrophy at the eight inch level as a result of static and dynamic training.

<u>Cross-Transfer</u>. Significant differences in the untrained leg when compared to the control for the angles tested provided evidence of cross-transfer of strength. No statistically significant difference in strength was found between the isotonic and the isometric groups at either angle. The trends of these changes are shown (Graphs 6 and 7). The mean increases for the isotonic group were twenty-four and twenty percent respectively at the 135 degree and the 115 degree angles and fourteen and fifteen percent at these same angles for the isometric group. These results are interesting in light of the fact that the difference in the increase between trained and untrained legs for the isotonic group was in the order of eight percent while the difference in the isometric group was in the order of two percent. The same percentage difference (i.e. 8% and 2%) existed at both angles measured.

INTERACTION

GRAPH 6

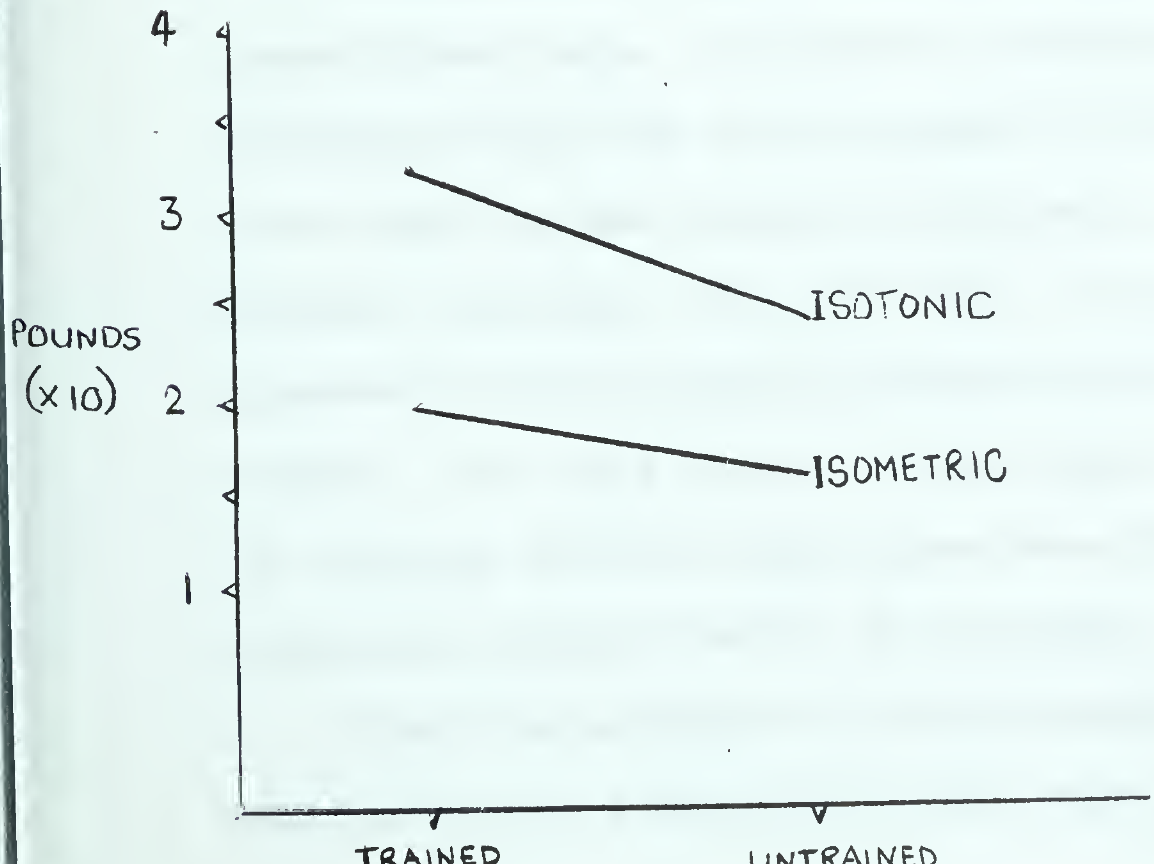


STRENGTH 135°

	TRAINED	UNTRAINED
ISOTONIC	41.3	26.6
ISOMETRIC	22.6	17.2

INTERACTION

GRAPH 7



STRENGTH 115°

	TRAINED	UNTRAINED
ISOTONIC	33.8	22.4
ISOMETRIC	21.2	17.6

Rose et al. (6) also found cross-transfer effects to the contralateral limb. With respect to this phenomenon they stated (6:160):

> In the normal well motivated individual the strength of the unexercised quadriceps was almost exactly the same as that found in the exercised muscle. In others, the strength of the unexercised muscle was 10 to 15 per cent less than that of the exercised side.

Lawrence et al. (1) have also found significant cross-transfer effects in strength in the quadriceps by both isotonic and isometric exercises. Depending on the method used for training, whether isometric or isotonic, they found gains in the unexercised leg ranging from sixty-five to one hundred percent of the gain in the trained legs. In two of the three tests employed greater gains were observed in the isotonic groups. These differences were not statistically significant.

Petersen (4) however, found no cross-transfer to the unexercised legs. It must be remembered that in the Petersen study the only increase in strength in the exercised leg was found in the group exercised by heavy dynamic training. The fact that cross-transfer was not observed in this training method is not known. It was, however, the only study reviewed where cross-transfer of strength did not take place when the exercised leg had gained significantly in strength.

When the effects of cross-transfer in terms of muscular endurance were evaluated it was seen that when muscular

endurance was measured by the first method (i.e. 5/8 initial strength used for both initial and final tests) there was realistically no change in the muscular endurance of the untrained leg (Graph 8). When the second way of evaluating muscular endurance was used (5/8 initial strength as weight for initial test and 5/8 final strength as weight for final test) the untrained leg made a significant decrease in muscular endurance (Graph 9). It was the resultant change in final strength, however, that produced this decrease.

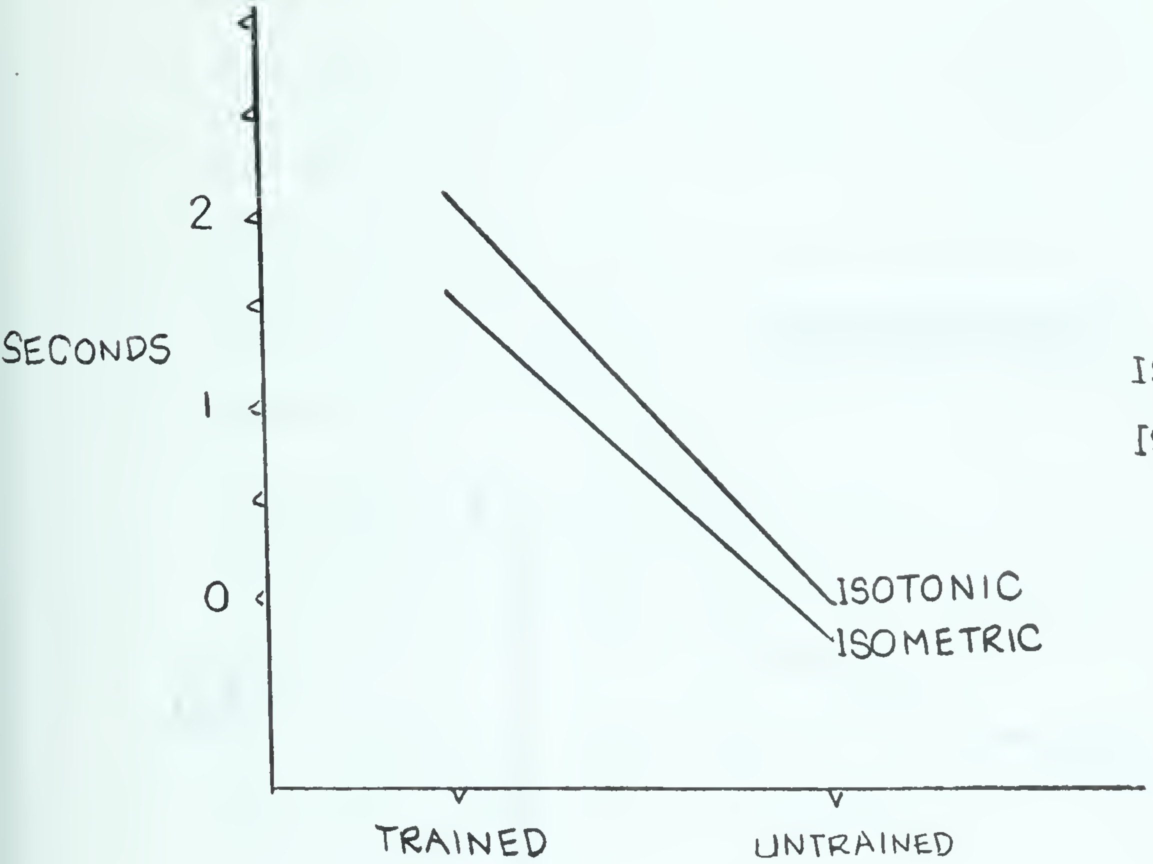
It was observed that the increases in strength occurred in both trained and untrained legs whereas the muscular endurance increased only in the trained leg when measured by the first endurance method. There was no significant cross-transfer effect in girth (Graph 10).

Specificity and Training Angles. It has been generally suggested that greater strength changes result when the angle that has been used to train the subject is used as the measuring angle. For this reason a measurement angle (115 degrees) other than the one the isometric group trained at was used to test the strength. It was found that both isotonic and isometric groups gained significantly at this angle.

It was noted that the isotonic group gained significantly over the isometric group ($F = 6.26_{.05}$) at the 135 degree angle, but there is no significant difference between the two experimental groups at the 115 degree angle. The significant

INTERACTION

GRAPH 8

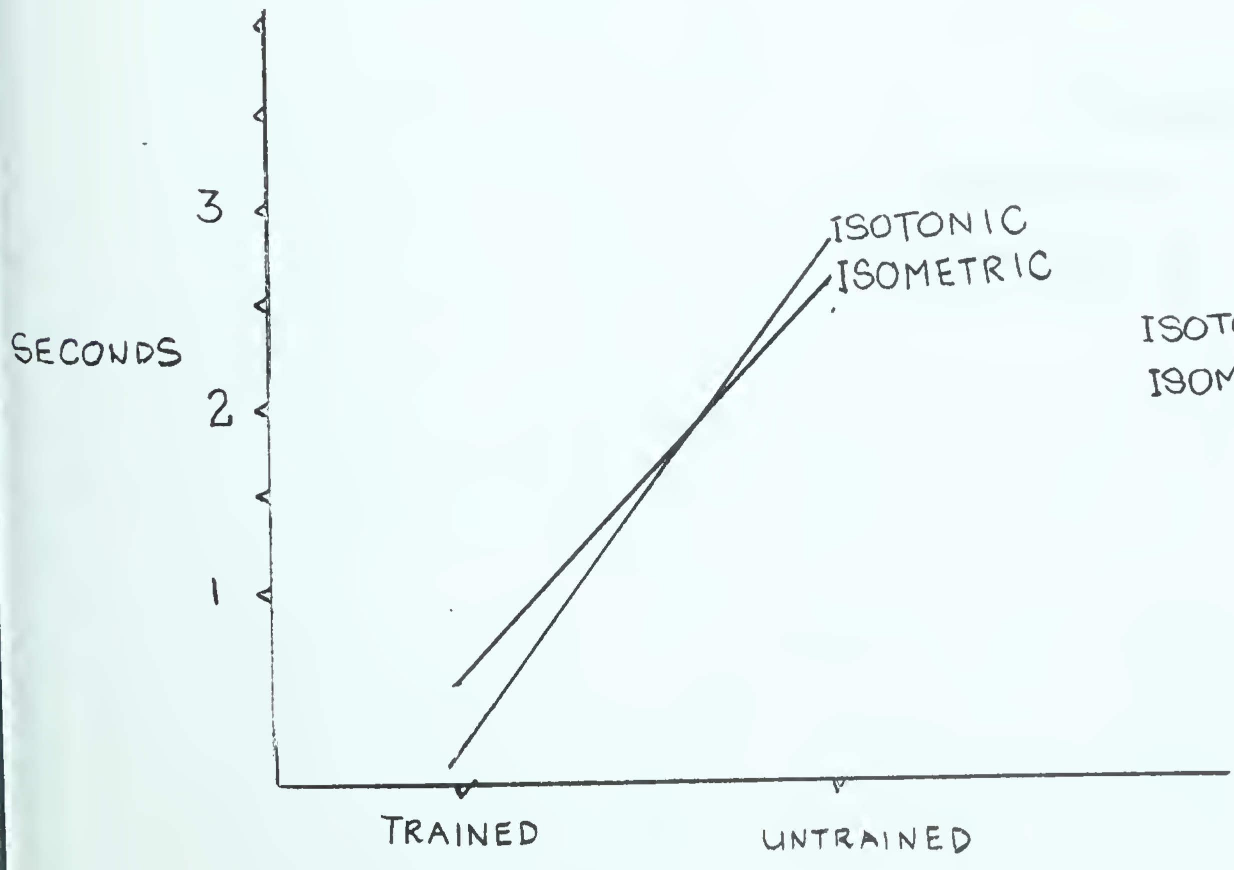


MUSCLE ENDURANCE I

	TRAINED	UNTRAINED
ISOTONIC	-20.2	-1.5
ISOMETRIC	-17.2	-1.7

INTERACTION

GRAPH 9

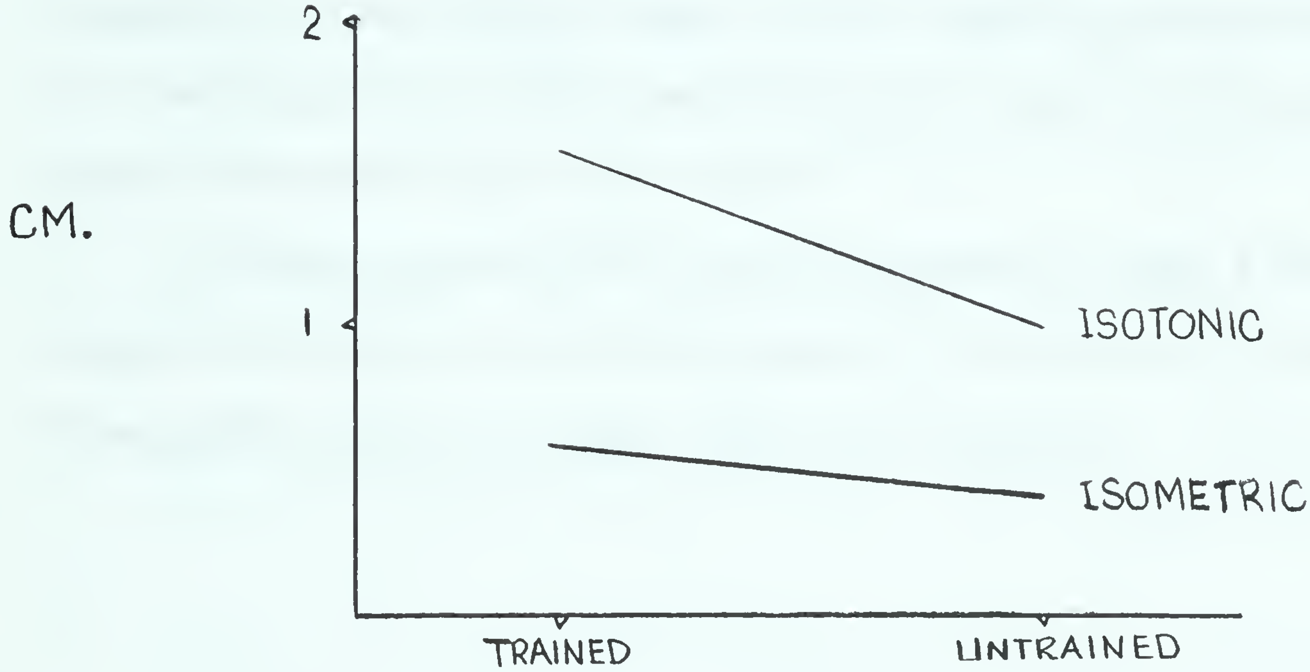


MUSCLE ENDURANCE 2

	TRAINED	UNTRAINED
ISOTONIC	-1.7	27.8
ISOMETRIC	-5.1	26.1

INTERACTION

GRAPH 10



GIRTH

	TRAINED	UNTRAINED
ISOTONIC	-1.5	1.0
ISOMETRIC	-.6	.5

difference at the 135 degree angle may have resulted from the fact that some of the subjects in the isometric group complained of muscle soreness when they contracted maximally at that angle on the final test. This discomfort may have limited the potential maximal voluntary effort. This soreness was also reported by a few of the subjects in the isometric group during some of the training sessions. None of the subjects in the isotonic group nor in the control group reported this difficulty.

Although specificity did not seem to play a very important part in the development of strength, no definite conclusions may be drawn from the evidence.

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CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effect of short periods of maximal isometric and isotonic contractions on the development of strength and muscular endurance of the quadriceps. Subproblems concerning hypertrophy, cross-transfer and specificity arising out of the main investigation were also considered.

Sixty grade ten boys from Bonnie Doon High School in the city of Edmonton served as the subjects. They were randomly divided into three groups; an isotonic training group, an isometric training group, and a control group. Each group contained twenty subjects.

The isometric exercise programme consisted of three, six-second maximal contractions daily. One contraction was made at 90 degrees flexion, one at 135 degrees extension, and one at 165 degrees extension.

The isotonic group carried a maximal weight from the 90 degrees flexion position to the 165 degrees extension position in a time period that required six seconds. At the end of this movement the weight was removed from the subject's leg. This movement was repeated three times daily. If the subject successfully performed the exercise for the three bouts then the next exercise day he received

an additional one and one-quarter pound increment weight which served to establish a new maximal weight.

The initial and final tests for strength were measured on a specially constructed strain gauge exercise table at angles of 115 degrees and 135 degrees. The muscular endurance was measured by the holding time endurance. On the basis of the statistical analysis the following conclusions are justifiable:

1. The isotonic exercise group increased significantly over the isometric group at the 135 degrees angle and both increased significantly over the control group.
2. The isotonic and isometric groups increased significantly in strength over the control group at the 115 degrees angle. There was no statistically significant difference between the isometric and isotonic groups.
3. The muscular endurance holding time when measured by using the same amount of weight on both initial and final tests showed a significant improvement for the combined isotonic and isometric group scores of the trained leg when compared to the control.
4. The cross-transfer of strength was statistically significant for both isotonic and isometric exercise programmes at both angles measured. There was no cross-transfer of muscular endurance.

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APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Reliability of the Tests. Reliability coefficients, obtained by use of Pearson's Product - Moment correlation coefficient, were computed from the test-retest relults. The formula used was:

$$r = \frac{N\Sigma XY - \Sigma X - \Sigma Y}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2] \qquad [N\Sigma Y^2 - (\Sigma Y)^2]}}$$

where X = test score
Y = retest score

Analysis of Variance. The analysis of variance (1:227) was used to evaluate the significance of the difference scores (Final - Initial).

Sample Analysis of Variance.

Treatments	Subjects	Trained Leg	Untrained Leg	Total
A_1	1	2	7	9
	2	2	10	12
	.	.	.	.
	.	.	.	.
	.	.	.	.
	.	.	.	.
	n	6	12	18
A_2	1	5	16	21
	2	4	10	14
	.	.	.	.
	.	.	.	.
	.	.	.	.
	.	.	.	.
	n	11	13	24
A_3	1	3	7	10
	2	3	9	12
	.	.	.	.
	.	.	.	.
	.	.	.	.
	.	.	.	.
	n	7	10	17
	N	80	150	340

Sums of Squares

$$\text{Total (T)} = (2)^2 + (2)^2 + \ldots + (10)^2 - \frac{(340)^2}{N}$$

$$\text{Rows (R)} = \frac{(9)^2}{2} + \frac{(12)^2}{2} + \ldots + \frac{(17)^2}{2} - \frac{(340)^2}{N}$$

$$\text{Columns (C)} = \frac{(80)^2}{2n} + \frac{(150)^2}{2n} - \frac{(340)^2}{N}$$

$$\text{Rows x Columns (Rc)} = T - R - C$$

$$\text{Treatment (Tr)} = \frac{(\text{Rows Total } A_1)^2}{2n} + \frac{(\text{Rows Total } A_2)^2}{2n} + \frac{(\text{Rows Total } A_3)^2}{2n} - \frac{(340)^2}{N}$$

$$\text{Residual (S)} = R - Tr$$

$$\text{Between Cells (B)} = \frac{(\text{Total Sum Trained by } A_1)^2}{n} + \ldots + \frac{(\text{Total Sum Untrained by } A_3)^2}{n} - \frac{(340)^2}{N}$$

$$\text{Treatment x Column (TrC)} = B - Tr - C$$

$$\text{Residual (M)} = Rc - TrC$$

Summary - Analysis of Variance

Source of Variation	S.S.	d.f.	Mean Square	F
A: Treatment	Tr	(a-1)	$\frac{Tr}{(a-1)}$	$\frac{Tr/(a-1)}{S/a(n-1)}$
Error (a)	S	a(n-1)	$\frac{S}{a(n-1)}$	
B: Columns	C	(b-1)	$\frac{C}{(b-1)}$	$\frac{C/(b-1)}{M/a(n-1)(b-1)}$
AxB: Treatment x Columns	TrC	(a-1)(b-1)	$\frac{TrC}{(a-1)(b-1)}$	$\frac{TrC/(a-1)(b-1)}{M/a(n-1)(b-1)}$
Error (b)	M	a(n-1)(b-1)	$\frac{M}{a(n-1)(b-1)}$	
Total	T	nab-1		

Where a = treatments and b = trials and n = number in a group.

Orthogonal Comparison to Treatment Sums of the Analysis of Variance

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treatments	Coefficients				$\Sigma X_{k.}$		Products		
	$a_{.1}$	$a_{.2}$	$a_{.3}$	$a_{.4}$		$a_{.1}X_{k.}$	$a_{.2}X_{k.}$	$a_{.3}X_{k.}$	$a_{.4}X_{k.}$
1_a	-1	1	-1	1	X_1	$-X_1$	X_1	$-X_1$	X_1
1_b	-1	1	1	-1	X_2	$-X_2$	X_2	X_2	X_2
2_a	-1	-1	-1	-1	X_3	$-X_3$	$-X_3$	$-X_3$	$-X_3$
2_b	-1	-1	1	1	X_4	$-X_4$	$-X_4$	X_4	X_4
3_a	2	0	2	0	X_5	$2X_5$	0	$2X_5$	0
3_b	2	0	-2	0	X_6	$2X_6$	0	$-2X_6$	0
					$\Sigma = 340$				

$\Sigma a_{.i}$	0	0	0	0	D	$\Sigma(7)$	$\Sigma(8)$	$\Sigma(9)$	$\Sigma(10)$
$\Sigma a_{.i}^2$	12	4	12	4	D^2	$[\Sigma(7)]^2$	$[\Sigma(8)]^2$	$[\Sigma(9)]^2$	$[\Sigma(10)]^2$
$n\Sigma a_{.i}^2$	240	80	240	80	A	$\frac{D^2}{D} = A_1$	$\frac{D^2}{D} = A_2$	$\frac{D^2}{D} = A_3$	$\frac{D^2}{D} = A_4$

$$F_1 = \frac{A_1}{S/a(n-1)} \qquad F_3 = \frac{A_3}{M/a(n-1)(b-1)}$$

$$F_2 = \frac{A_2}{S/a(n-1)} \qquad F_4 = \frac{A_4}{M/a\ (n-1)(b-1)}$$

In order to compare the trained and untrained legs of the isometric and isotonic group taken together against the control the following test was used.

Dunnett's Test for Comparisons With a Control (1:152).

Treatment	Trained Leg	Untrained Leg
A_1	$\bar{X}_{t1}$	$\bar{X}_{u1}$
A_2	$\bar{X}_{t2}$	$\bar{X}_{u2}$
A_3	$\bar{X}_{t3}$	$\bar{X}_{u3}$

Standard Error of a Comparison.

$$S_{\bar{X}_o - \bar{X}_k} = \sqrt{\frac{2\ (\text{mean square within groups})}{n}}$$

where $S_{\bar{X}_o} - \bar{X}_k$ is equal to the standard error of the difference between two means, and n is equal to the number of subjects in a given group.

Tests of Significance.

Let the required t taken from tables for one-sided treatment means and a control for a joint confidence coefficient of P = 95% or 99% = t

$$\bar{X}_k. - \bar{X}_o. \geq (t)\ (S_{X_o} - X_k)$$

For any difference between a treatment mean and a control mean to be judged significant, the difference $\bar{X}_k - \bar{X}_o$ must be equal to or greater than (t) ($S_{\bar{X}_o} - \bar{X}_k$).

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APPENDIX B

ELECTRICAL CIRCUITS

STRAIN GAUGE

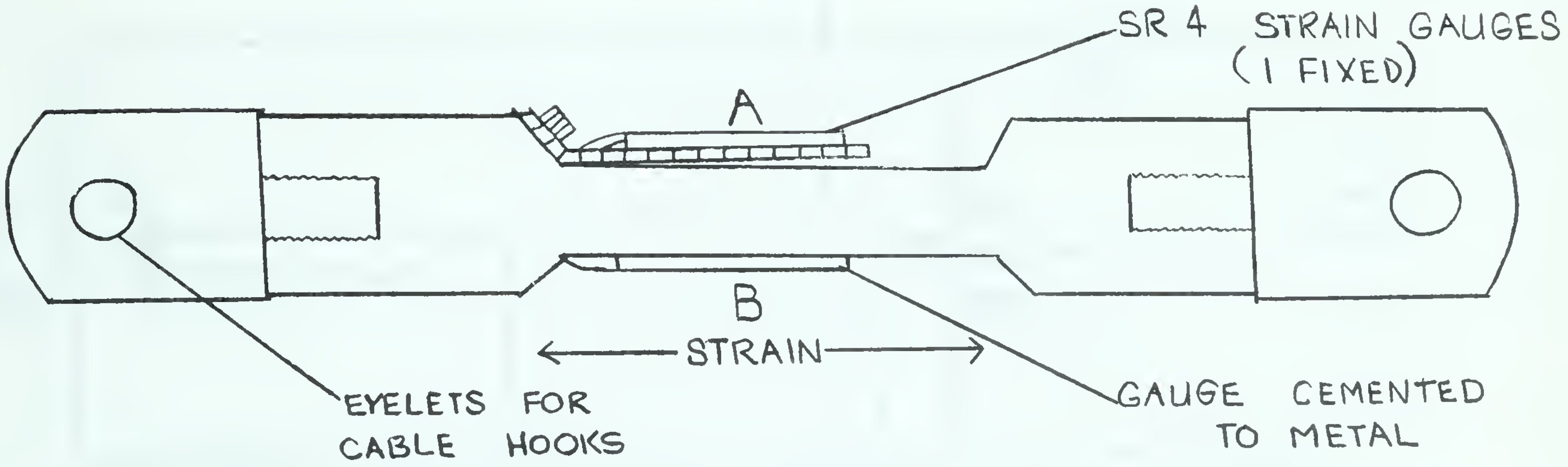
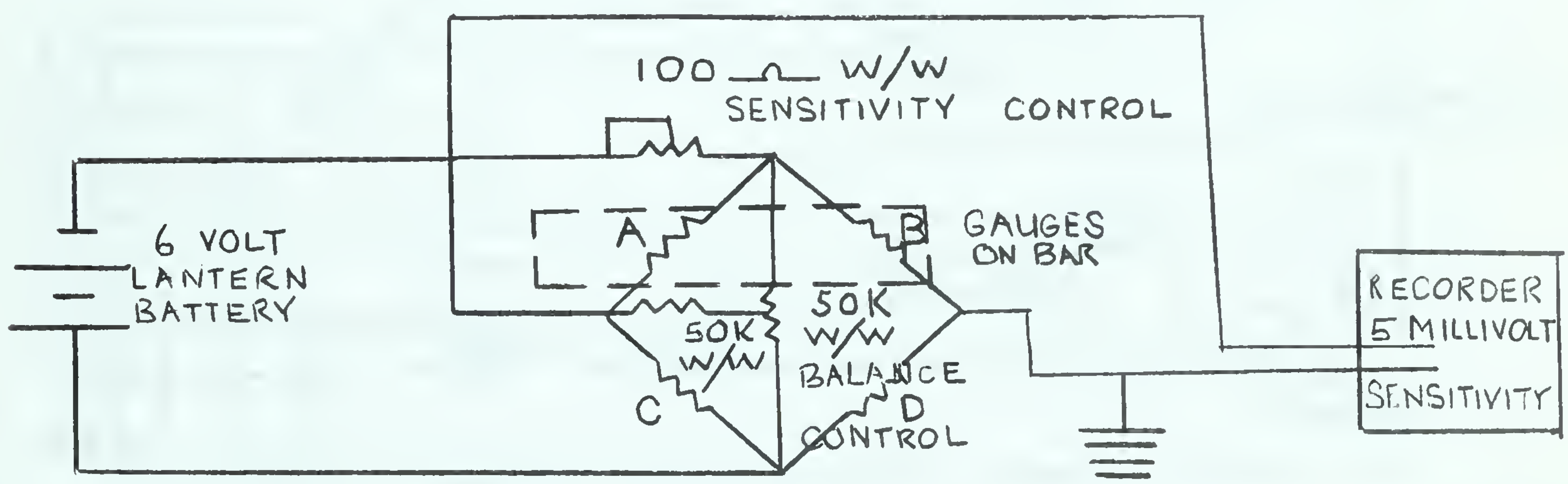


DIAGRAM A

STRAIN GAUGE CIRCUIT



A B C D - SR 4 GAUGES
A AND B ARE MOUNTED ON THE GAUGE UNITS THEMSELVES, WITH B FIXED AND USED ONLY FOR TEMPERATURE COMPENSATION.

DIAGRAM B

POTENTIOMETER CIRCUIT

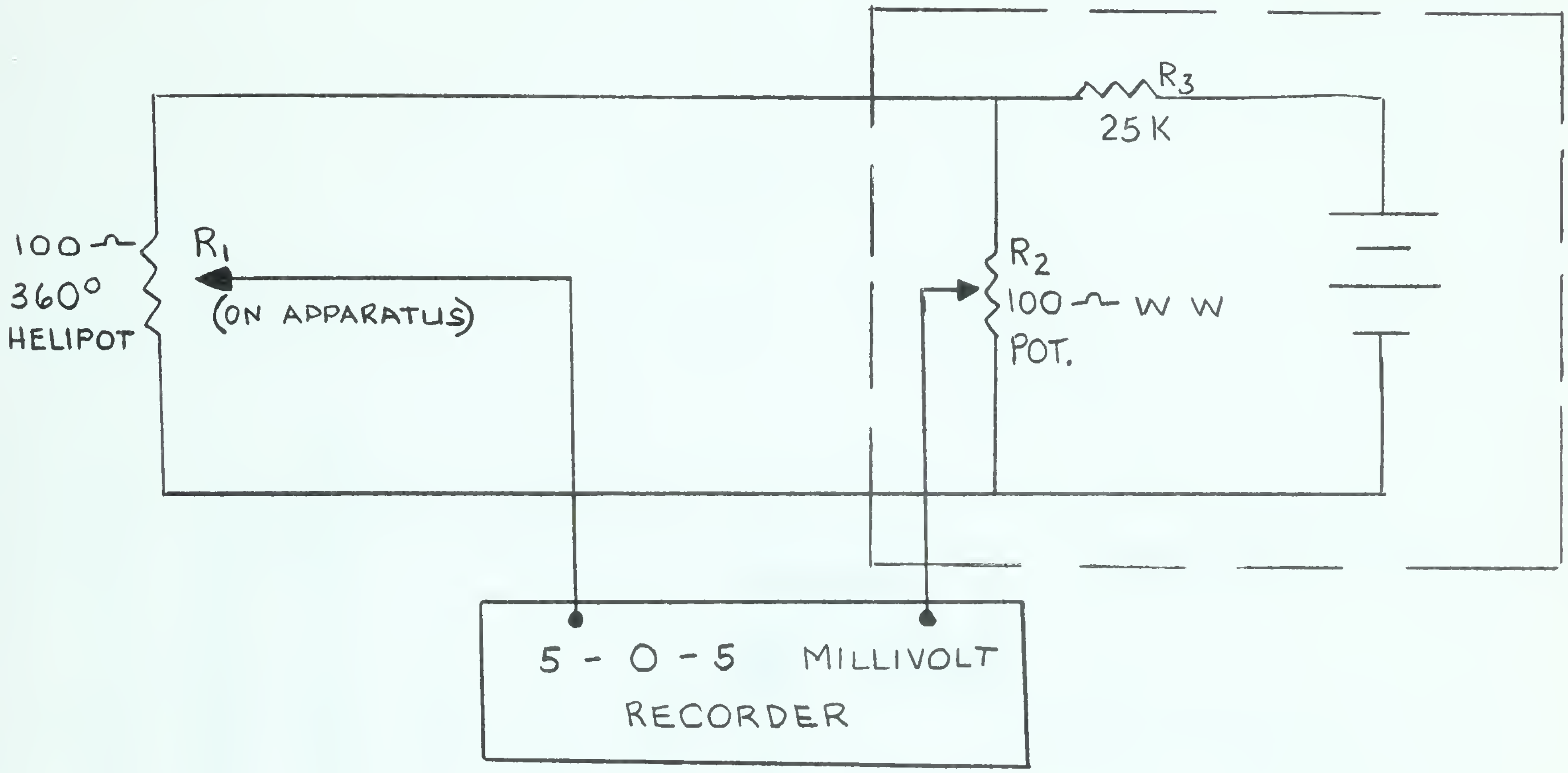


DIAGRAM C

CONTROL BOX CIRCUIT

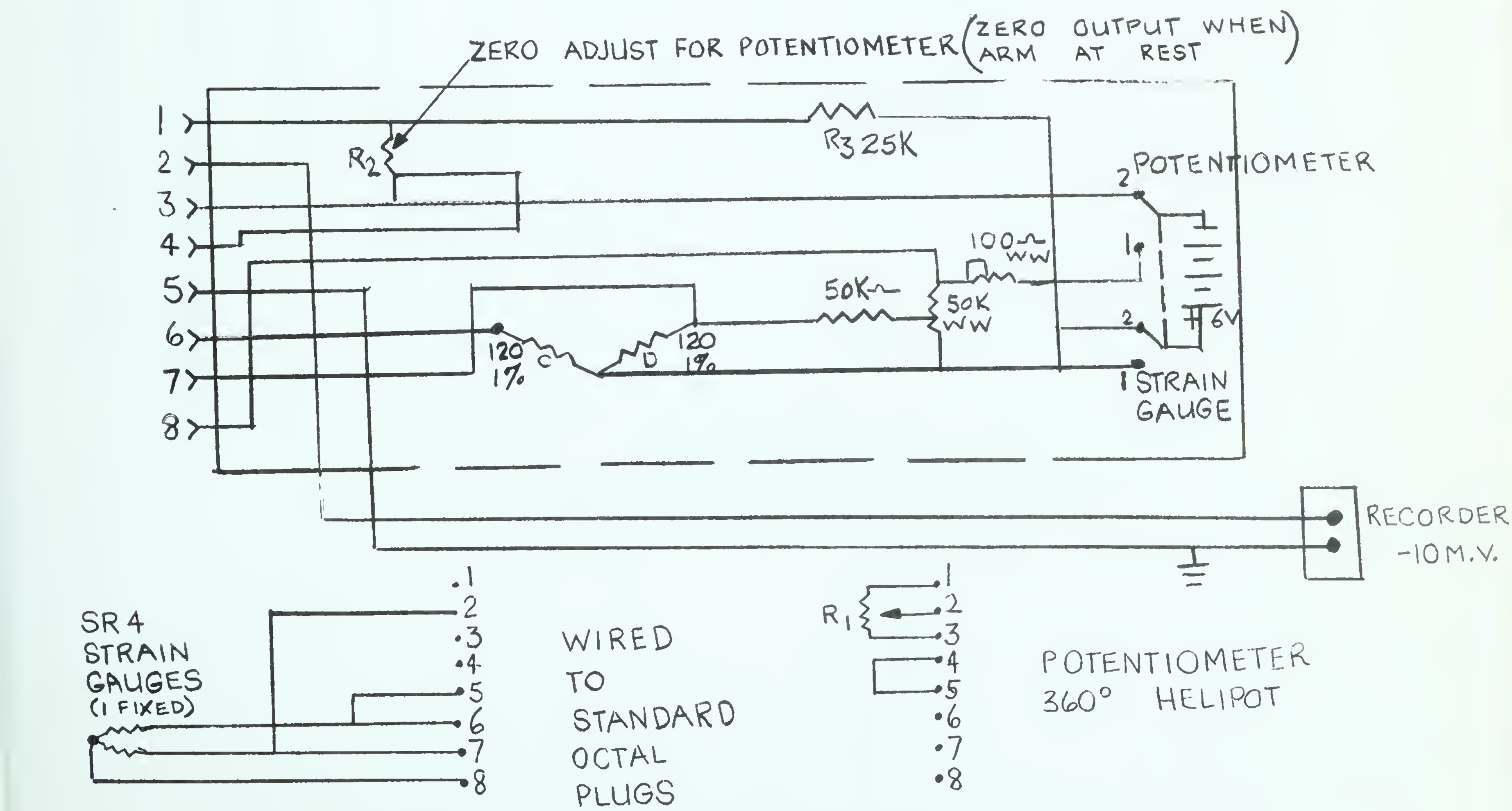


DIAGRAM D

APPENDIX C

RAW SCORES

STRENGTH

115°

lbs.

No.	Isotonic				Isometric				Control			
	Initial		Final		Initial		Final		Initial		Final	
	D	O	D	O	D	O	D	O	D	O	D	O
1	170	156	240	195	160	152	212	158	178	155	177	152
2	154	102	167	111	168	125	154	156	173	148	178	148
3	140	190	149	195	138	120	160	136	173	129	175	128
4	146	129	160	148	146	130	206	198	152	146	154	153
5	130	113	134	116	172	143	189	149	166	111	167	110
6	120	158	168	160	138	129	176	160	146	138	145	137
7	125	114	138	112	140	135	164	145	156	123	155	119
8	114	114	157	155	127	127	125	120	124	118	117	120
9	115	113	147	140	140	108	98	90	126	135	123	134
10	120	125	160	119	105	95	123	137	134	132	160	154
11	123	130	160	177	138	120	170	116	118	108	137	111
12	82	94	112	95	80	120	87	127	134	122	145	135
13	93	115	160	174	97	95	124	143	102	96	100	96
14	110	94	176	152	95	105	133	134	135	132	137	130
15	113	107	127	108	113	122	133	150	95	86	100	90
16	123	100	140	115	100	105	152	115	99	95	97	95
17	117	103	116	95	80	118	109	123	92	126	100	125
18	84	80	132	111	80	62	84	87	96	97	96	98
19	80	80	126	132	90	82	125	102	96	103	105	102
20	73	60	140	115	120	100	127	100	65	76	70	90

D - Dominant leg (trained leg for isometric and isotonic groups.)

O - Opposite leg (untrained leg for isometric and isotonic groups.)

STRENGTH

135°

lbs.

No.	Isotonic				Isometric				Control			
	Initial		Final		Initial		Final		Initial		Final	
	D	O	D	O	D	O	D	O	D	O	D	O
1	226	186	252	209	212	178	220	186	202	190	205	193
2	175	152	191	173	192	140	220	166	172	122	172	117
3	106	89	190	155	173	150	170	156	172	172	173	172
4	165	155	186	155	169	132	217	214	170	155	170	153
5	100	91	162	160	164	126	178	126	166	130	166	126
6	154	135	194	153	156	134	189	142	167	160	165	159
7	153	118	165	123	152	140	206	200	142	107	138	98
8	144	120	180	132	147	138	164	120	152	152	157	156
9	140	132	175	133	140	128	145	129	140	145	137	143
10	140	122	150	125	140	114	158	135	139	140	165	160
11	138	120	182	172	140	127	140	131	140	140	144	143
12	83	55	120	102	135	132	137	120	134	113	130	119
13	120	100	200	168	122	112	135	125	134	120	137	123
14	116	112	180	140	118	107	177	146	130	125	128	124
15	113	113	182	112	113	113	153	128	115	90	110	94
16	111	85	153	110	110	83	166	100	103	100	104	100
17	109	84	112	85	107	102	140	105	110	138	110	140
18	100	92	169	112	105	58	111	85	108	100	110	97
19	97	95	119	107	100	65	135	107	93	92	98	97
20	85	52	140	115	138	117	124	120	82	74	90	80

HOLDING TIME

Endurance -1

seconds

No.	Isotonic				Isometric				Control			
	Initial		Final		Initial		Final		Initial		Final	
	D	O	D	O	D	O	D	O	D	O	D	O
1	64	125	92	92	74	95	55	93	69	80	73	90
2	94	90	72	69	109	107	74	92	86	146	85	128
3	113	146	124	133	109	140	134	139	45	51	49	59
4	35	44	40	71	46	96	102	127	42	46	43	51
5	86	112	70	52	120	116	122	117	71	52	70	58
6	60	65	74	75	64	77	75	81	89	96	91	94
7	40	57	76	81	113	112	152	143	51	126	51	115
8	55	120	101	116	137	154	124	124	63	93	73	90
9	114	85	90	61	92	90	60	71	117	140	118	125
10	80	96	125	149	34	63	48	35	91	134	89	125
11	102	134	70	95	67	97	77	77	126	98	124	107
12	78	235	184	181	63	80	48	60	126	187	123	138
13	144	147	96	111	113	98	94	96	58	92	60	89
14	86	79	73	73	97	92	221	213	130	180	120	175
15	51	64	95	88	82	108	159	159	99	95	101	110
16	116	117	135	71	110	69	150	95	134	143	110	139
17	45	131	75	161	190	160	148	104	68	84	79	94
18	84	85	105	78	72	172	101	151	67	97	82	111
19	57	83	155	132	156	229	96	128	125	139	114	124
20	120	238	176	327	48	137	162	141	78	90	81	95

For the final test the same weight as the initial was held.

HOLDING TIME

Endurance -2

seconds

No.	Isotonic Initial D	Isotonic Initial O	Isotonic Final D	Isotonic Final O	Isometric Initial D	Isometric Initial O	Isometric Final D	Isometric Final O
1	64	125	63	116	74	95	74	67
2	94	90	104	103	109	107	96	55
3	113	146	99	100	109	140	100	126
4	35	44	47	46	46	96	82	132
5	86	112	97	62	120	116	114	110
6	60	65	28	35	64	77	65	74
7	40	57	44	58	113	112	90	80
8	55	120	113	93	137	154	100	156
9	114	85	100	86	92	90	83	83
10	80	96	98	135	34	63	51	35
11	102	134	68	103	67	97	75	35
12	78	235	130	88	63	80	55	83
13	144	147	46	60	113	98	91	96
14	86	79	60	135	97	92	167	122
15	51	64	80	85	82	108	78	72
16	116	117	79	92	110	69	63	73
17	45	131	98	102	190	160	87	50
18	84	85	66	81	72	172	65	73
19	57	83	73	67	156	229	142	145
20	120	238	96	49	48	137	106	103

For the final test a weight equivalent to five-eighths of the strength determined on the final test was held.

FAT CORRECTED GIRTH SCORES

Dominant Isotonic

No.	Initial Girth (cm.)	Initial Fat (mm.)	Initial Fat Corrected (cm.)	Final Girth (cm.)	Final Fat (mm.)	Final Fat Corrected (cm.)
1	58.3	15.2	55.92	59.3	16.5	56.72
2	47.5	8.7	46.14	50.8	8.4	49.49
3	48.9	9.3	47.44	51.5	8.9	50.11
4	46.2	6.8	45.14	50.3	7.5	49.13
5	49.1	15.0	46.75	49.7	15.1	47.33
6	51.7	10.5	50.06	53.4	10.1	51.82
7	53.1	9.4	51.63	52.2	11.0	50.48
8	50.2	17.1	47.52	53.9	16.2	51.36
9	50.0	6.1	49.05	54.5	6.7	53.45
10	55.8	17.3	53.09	53.5	17.3	50.71
11	53.2	13.7	51.05	52.2	13.6	50.07
12	46.6	8.6	45.25	48.8	9.6	47.30
13	44.8	8.3	43.50	49.0	7.7	47.80
14	50.3	13.6	48.17	51.9	12.1	50.00
15	48.9	9.2	47.46	47.9	11.0	46.26
16	49.7	9.6	48.20	50.2	10.3	48.59
17	48.8	12.3	46.87	51.1	12.1	49.21
18	47.7	9.1	46.29	48.7	9.0	47.29
19	47.2	17.3	44.49	49.4	14.2	47.17
20	44.9	13.0	42.86	45.9	14.9	43.56

FAT CORRECTED GIRTH SCORES

Opposite Isotonic

No.	Initial Girth (cm.)	Initial Fat (mm.)	Initial Fat Corrected (cm.)	Final Girth (cm.)	Final Fat (mm.)	Final Fat Corrected (cm.)
1	58.4	15.6	53.96	58.9	17.1	56.22
2	47.4	9.1	45.98	47.7	9.6	46.20
3	48.3	9.1	46.88	50.1	8.7	48.74
4	45.1	7.1	43.99	49.5	8.1	48.24
5	49.1	16.0	46.59	49.3	15.3	46.90
6	50.2	11.2	48.45	51.2	11.1	49.48
7	53.4	9.4	51.93	54.7	12.1	52.67
8	50.2	18.8	47.25	52.0	19.4	47.16
9	47.7	6.9	46.62	52.6	6.9	51.52
10	54.5	17.5	51.76	53.0	17.8	50.21
11	52.1	15.2	49.72	51.3	14.0	49.11
12	46.8	7.8	43.99	50.4	8.1	48.24
13	44.3	8.3	43.00	48.4	7.8	47.18
14	50.7	15.5	48.27	51.3	12.4	49.36
15	48.9	9.3	47.44	48.9	11.0	47.18
16	50.3	10.2	48.70	50.3	11.3	45.39
17	48.6	14.2	46.38	50.8	14.1	48.45
18	47.5	8.9	46.11	47.3	9.2	45.86
19	46.4	17.4	43.67	47.3	14.4	45.04
20	44.8	14.0	42.61	46.1	13.1	44.05

FAT CORRECTED GIRTH SCORES

Dominant Isometric

No.	Initial Girth (cm.)	Initial Fat (mm.)	Initial Fat Corrected (cm.)	Final Girth (cm.)	Final Fat (mm.)	Final Fat Corrected (cm.)
1	52.4	9.3	50.95	52.3	8.9	50.91
2	52.9	9.1	51.48	55.9	7.3	54.76
3	53.7	11.1	51.96	50.9	14.5	48.63
4	50.8	6.3	49.82	52.5	7.5	51.33
5	51.7	10.6	50.04	49.7	10.9	47.99
6	54.7	14.5	52.43	57.8	13.2	55.73
7	49.5	8.7	48.14	47.5	9.9	45.95
8	49.9	7.1	48.79	50.9	7.9	49.67
9	50.1	11.4	48.31	47.6	10.2	46.01
10	47.9	15.0	45.55	51.0	16.8	48.37
11	53.6	12.4	51.66	53.5	11.6	51.69
12	49.3	9.5	47.81	50.4	11.5	48.60
13	50.3	8.8	48.92	51.9	8.6	50.55
14	52.8	15.8	50.32	52.1	15.7	49.64
15	47.9	11.5	46.10	49.9	11.6	48.09
16	55.2	25.9	51.14	56.0	21.2	52.68
17	41.2	17.2	40.07	43.5	9.0	42.09
18	44.9	21.2	41.57	46.8	23.9	43.05
19	45.8	11.5	49.00	44.4	11.3	42.63
20	48.2	10.8	46.51	51.5	12.0	49.62

FAT CORRECTED GIRTH SCORES

Opposite Isometric

No.	Initial Girth (cm.)	Initial Fat (mm.)	Initial Fat Corrected (cm.)	Final Girth (cm.)	Final Fat (mm.)	Final Fat Corrected (cm.)
1	51.9	8.9	50.51	51.9	8.7	50.54
2	52.7	9.2	51.26	54.3	7.4	53.14
3	52.3	12.4	50.36	49.0	15.0	46.65
4	49.7	6.6	48.67	52.2	8.4	50.89
5	51.5	14.0	49.31	49.0	11.7	47.17
6	53.2	16.0	50.69	54.9	19.4	51.86
7	50.3	8.7	48.94	49.2	9.8	47.67
8	49.7	7.0	48.61	50.7	7.8	49.48
9	49.8	11.0	48.08	46.8	9.5	45.31
10	47.9	15.1	45.53	49.9	15.7	47.44
11	54.4	12.1	52.51	53.5	12.1	51.61
12	49.5	11.7	47.67	49.3	11.6	47.49
13	49.1	9.2	47.66	49.7	9.2	48.26
14	52.0	15.6	49.56	52.9	16.8	50.27
15	48.0	11.8	46.15	48.7	11.2	46.95
16	56.5	26.6	52.33	55.4	21.2	52.08
17	41.7	7.5	40.53	43.1	8.2	41.82
18	45.8	16.4	43.23	47.1	19.3	44.07
19	44.4	12.8	42.33	45.3	15.3	42.90
20	45.1	10.9	43.40	52.9	11.3	51.13

CORRECTION OF THIGH CIRCUMFERENCE FOR SUBCUTANEOUS FAT

Sample Calculation

Circumference of thigh:		58.3cm.
Double thigh skinfold thickness:		15.2mm.
Diameter of thigh:	$\frac{58.3}{3.1416}$	18.55cm.
Diameter of thigh corrected for fat:	$18.55 - \frac{15.2}{2 \times .1}$	17.99cm.
Circumference of thigh corrected for fat:	17.79 X 3.1416	55.92cm.